A STUDY OF THE STEEL FIBRE REINFORCED CONCRETE (SFRC) WITH MICROWAVE INCINERATOR RICE HUSK ASH (MIRHA)

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by

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CERTIFICATION OF APPROVAL

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Approved by,

(AP Ir. Dr. Hj Muhd Fadhil b. Nuruddin)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SHEIRMAN ROZAIDI SHAZULA

ABSTRACT

Concrete in its simplest explanation is a composite construction material made from the combination of aggregates admixtures and cementitious binder. Various types of concrete have been developed for special application and the most common ones are plain concrete, steel fibre concrete, self-compacting concrete and asphalt concrete. It is now well established that one of the important properties of Steel Fibre Reinforced Concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fibre composites possess increased extensibility and tensile strength, both at first crack and at ultimate, and the fibres are able to hold the matrix together even after extensive cracking

This research provides an insight on the effects of steel fibre and Microwave Incinerator Rice Hush Ash (MIRHA) to concrete properties. Concrete is a material which has high compressive strength. However, the tensile strength is estimated to be only 10 per cent of the compressive strength. Basically, there are three main tests performed in this study to determine the properties of the concrete, which are Compressive Test, Splitting Tensile Test and Porosity Test. The tests are done at 3rd day, 7th day, 28th day and 56th days with different grade of concrete (G25, G50 & G70) with different percentage of steel fibre (0%, 0.3% 0.5% and 0.8%) and 5% of MIRHA inclusions.

The test results indicate the improvement on compressive strength and tensile strength of concrete in presence of steel fibre and MIRHA. Visual observations also revealed the improvement on crack pattern of concrete after introducing the steel fibre. This research also found the optimum proportion of steel fibre was 0.5%, which gave the highest improvement of tensile strength (about 40%). The improvement of compressive strength (about 20%) occurred after introducing the 5% of MIRHA to concrete. The most significant improvement of concrete properties was observed at concrete Grade 25.

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CHAPTER 1

INTRODUCTION

1.1 General

Concrete is a composite material which mainly consists of aggregate particles and binding agents. It can also contain admixtures and additives which improve the properties of freshly-mixed or hardened concrete. Concrete has been the largest construction material used in the largest quantity for several decades. The reason for its popularity can be found in the excellent technical properties of concrete as well as in the economy of this material. It is also characteristic that the properties of concrete ingredients have a major influence on the fresh as well as hardened concrete. These properties of the concrete in its fresh state prior to hardening are extremely important for the workability of the material because it will affect the bearing capacity and deformation properties of the structure for which it is used to build.

Concrete also has an excellent capacity for compressive stress. Its tensile strength is, however, much lower and depends on many factors, particularly the bonding of the aggregate particles to the hardened cement paste.

Concrete is generally referred to as a heterogeneous and discontinuous material and is formed primarily by mixing three constituents, namely aggregate, cement and water. Coarse and fine aggregates are bound together by the adhesive character of cement paste into a rock-like mass, concrete. Due to the different components that interact with each other during the formation stage, the heterogeneous nature of concrete is unavoidable. As a result, concrete suffers from microcracks and flaws including pores, air voids, lenses of bleed water and shrinkage cracks even in the unloaded stage. When external loading is applied, these microcracks grow and coalesce with new microcracks leading to the failure of the structure or member.

1.2 Background Study

Nowadays, the usage of concrete is increasing from time to time due to the rapid development of construction industry. The usage of concrete is not only in building construction but also in other areas such as road construction, bridges, tunneling and many more. Thus, technology in concrete has gained much momentum and its technology has developed into many facets for the betterment of quality and properties of concrete. Portland cement concrete is considered to be a relatively brittle material. When subjected to tensile stresses, non-reinforced concrete will crack and fail. Since mid 1800's steel reinforcement has been used to overcome this problem. As a composite system, the steel reinforcement is assumed to carry all tensile loads.

The problem with employing steel in concrete is that over time steel corrodes due to the ingress of chloride ions and/or carbonation. Although some measures are available to reduce corrosion of steel in concrete such as corrosion inhibitive admixtures and coatings, a better and permanent solution may be to replace the steel with a reinforcement that is less environmentally sensitive. More recently micro fibers, such as those used in traditional composite materials have been introduced into the concrete mixture to increase its toughness, or ability to resist crack growth.

Research represented the first significant steps towards development of steel fibre concrete (Romualdi, Batson, and Mandel, 1960). Although patents have been granted since the turn of the century for various methods of reinforcing concrete with steel, development of steel fibre concrete technology did not progress much until the late 1950's. The actual origins of SFRC go back more than one hundred years. A long process of development began for a material which, on the one hand, can be shaped into any required form and, on the other, meets extensive requirements in terms of strength and deformation behavior (A. Berard, 1874).

1.3 Problem Statement

Reinforced concrete is generally a strong material that is used in many structure constructions. It is highly durable and can be formed into various shapes and size ranging from a simple rectangular column, to a slender curved dome or shell. The tensile strength of concrete is approximately 10 per cent of the compressive strength. In application, the concrete is reinforced together with steel in order to govern the tensile force (see **Figure 1.1**). In design of concrete elements, the tensile strength of concrete is not taken into consideration and commonly taken as zero for the safety factor.

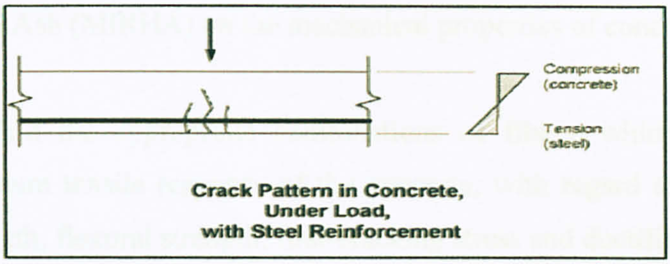


***Figure 1.1**: Steel reinforcement in beam*

Generally, microcracks start to generate in the concrete at about 10-15 percent of the ultimate load and it propagates into macrocracks at about 25-30 percent of the ultimate load (Deacon, 1991). As the consequence, concrete structural element cannot be expected to sustain large transverse loading without the addition of reinforcement bar in the tensile zone of the structure such as beams or slabs. However, by using the steel reinforcement bar alone cannot arrest or slow down the development of microcracks and macrocracks.

The design of a composite possessing high strength, large ductility, long lasting durability and low cost is highly demanded by the construction industry today. Recent research indicates that high performance fiber cementitious composites will be the materials of the future. In this study, the durability of Steel fibre Reinforced Concrete (SFRC) with Microwave Incinerator Rice Husk Ash (MIRHA) will be investigated. It is expected that the results obtained will encourage the construction industry in Malaysia and also in other countries to expand the use of steel fiber and also MIRHA without fear of reduction in performance. It is also hoped that the findings of this study will be used to aid selection of the optimum proportion of steel fibre and MIRHA.

1.4 Objectives

The objectives of this study are as follow:-

- To identify the influence of steel fibre and Mircrowave Incinerator Rice Hush Ash (MIRHA) on the mechanical properties of concrete
- To find the appropriate combinations of fibers, which can ensure an optimum tensile response of the concrete, with regard to uniaxial tensile strength, flexural strength, first-cracking stress and ductility.
- To identify the optimum percentage inclusion of steel fibre into concrete on their tensile properties and workability.
- To identify the crack pattern of concrete samples before and after introducing steel fibre and MIRHA

1.5 Scope of Works

Basically, the scope of work encompasses two (2) mainly parts which are:-

- Fresh Concrete Test
  - Slump Test
- Hardened Concrete Test
  - Compressive Strength Test
  - Tensile Strength Test
  - Porosity Test

The tests were investigated on variable grades of concrete (G25, G50 and G70) and different percentages of steel fibre (0.0%, 0.3%, 0.5%, 0.8%). All these mixtures were done with 5% inclusion of MIRHA.

The compressive strength tests are done in cube sample of 150mm size while the splitting tensile tests were done on 100mm cylinder with 200mm long. The cored samples of 50mm of diameter with 50mm thickness were done for porosity test. All the tests were done on 3rd, 7th, 28th, and 56th of curing day except for porosity test which only for 28th day of curing day.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature reviewed in this project consists of three parts. The first part provides a background on Fiber Reinforced Concrete (FRC), including its definition, characteristics, and mechanical performance, the second part provides a background on Rice Hush Ash (RHA), whereas the last part deals with testing to be conducted to determine the properties of the concrete.

The concrete industrial ground-floor slab is a key structural element in most industrial enterprises. It has two functions: first to sustain the operational loads from loaded racking system, goods stored directly on the floor, fork-lift truck wheel loads and mezzanine floors, and transfers them to the supporting soil without any structural failures or unaccepted settlements; second to provide a suitable wearing surface upon which the operations in the facility may be carried out efficiently and safely. This dual role of industrial ground-floor slab has concentrated attention on its critical contribution to the success of modern commercial facilities (Neal, 2002).

The art of designing most industrial floors is to provide sufficient reinforcement to control the amount and size of cracks to a level consistent with the intended use of the floor (Deacon, 1991). For this purpose, over very many years standardised welded steel fabric has become the traditional choice for the reinforcement of ground floor slabs, but during recent years, with the development of fast-track construction such as laser-screed machines, the use of fibres in flooring concrete has increased. The main purpose of adding any of fibre types to concrete is not to prevent cracking but to control it. The two main types of fibre that have been used around the world for many years in concrete structures, including floor slabs, are polypropylene and steel.

Various fibre-reinforcing materials are available nowadays, but structural applications of fibre-reinforced concrete are mainly made of steel fibre. More recently, new breeds of structural synthetic equivalents are proving their usefulness. Lighter weight, lower abrasion and better structural performance are making synthetic reinforcement an economic alternative. They are not in common use in floors but are an interesting development in fibre reinforcement technology (Concrete Society, 2003). Due to uncertainty, reflected in current design practice, over the ability of structural synthetic fibre to replace fabric or fibre reinforcement the need for an extensive research programme is encouraged.

2.2 Fibre Reinforced Concrete

2.2.1 General

Fibre reinforced concrete (FRC) is a composite material consisting not only of cement paste, sand, and aggregate but also of short threadlike fibre of steel, glass, polypropylene or other tension materials to create a composite with better performance. Similar to the role of ordinary reinforcement in concrete members, the addition of fiber reinforcement enhances the tensile characteristics of the concrete by inhibiting crack growth and thus improving its overall material and mechanical behavior. Such behaviors include substantial increase in toughness or energy absorption capacity in almost all failure modes (tension, compression and bending), tensile strength, fatigue and impact resistance and ductility. In fact it is generally agreed that increases in toughness and energy absorption capacity is the most important benefit of fiber reinforced concrete.

There are numerous fibre types, in various sizes and shapes, available for commercial and experimental use. The basic fibre categories are steel, glass, synthetic, and natural fibre materials. However, in slabs on grade, steel, polypropylene and structural synthetic fibre reinforced concrete is the main types of fibre, which are used as a replacement for conventional steel fabric reinforcement.

The use of FRC has been increasing steadily in recent years. As of 2001, over 76 million m^3 of FRC were produced annually, with the principal applications being ground slabs (60%), shotcrete (25%), and precast members (5%) and the remainder of the production distributed among a number of other specialty structural forms. A number of different types of fibers are used to produce FRC of various kinds. The most common ones are steel, organic polymers (primarily polypropylene), glass, carbon, asbestos, and cellulose. These fibres vary considerably in geometry, properties, effectiveness, and cost. Table 2.1 (S. Mindess, F. Young, Darwin, 1996) shows the typical properties of the most common fibre types:-

Fibre	Diameter (μm)	Specific Gravity	Modulus of Elasticity (GPa)	Tensile Strength (GPa)	Elongation at Break (%)
Steel	5-500	7.84	200	0.5-2.0	0.5-3.5
Glass	9-15	2.60	70-80	2.0-4.0	2.0-3.5
Polypropylene	6-200	0.90-0.91	5-77	0.15-0.75	15
Nylon	20-200	1.1	4.0	0.9	13-15
Polyethylene	25-1000	0.95-0.96	0.3	0.08-0.6	3-80
Polyster	18-360	1.34-1.39	17.5	0.89-1.10	11-13

***Table 2.1:** Types of Fibre*

Concrete contains numerous micro cracks. It is the rapid propagation of micro-cracks under applied stress that is responsible for the low tensile strength of the material. Initially, it was assumed that tensile as well as flexural strengths of concrete can be substantially increased by introducing closely spaced fibers which would obstruct the propagation of micro-cracks, therefore delaying the onset of tension cracks and increasing the tensile strength of the material. But experimental studies showed that with the volumes and sizes of fibres that could conveniently be incorporated into conventional mortars or concretes, the fibre reinforced products did not offer a substantial improvement in strength over corresponding mixtures without fibres (P.K. Mehta, 1986). Researchers, however, found considerable improvement in the post-cracking behavior of concretes containing fibers. In other words, although the ultimate tensile strengths did not increase appreciably, the tensile strains at rupture did. Thus compared to plain concrete, fibre reinforced concrete is much tougher and more resistant to impact.

2.2.2 Fibre Mechanisms

Fibres work with concrete utilizing two mechanisms: the spacing mechanism and the crack bridging mechanism. The spacing mechanism requires a large number of fibers well distributed within the concrete matrix to arrest any existing micro-crack that could potentially expand and create a sound crack. For typical volume fractions of fibres, utilizing small diameter fibres or micro fibres can ensure the required number of fibres for micro-crack arrest. The second mechanism, termed crack bridging, requires larger straight fibres with adequate bond to concrete. Steel fibres are considered a prime example of this fibre type that is commonly referred to as large diameter fibres or macro fibres. Benefits of using larger steel fibres include impact resistance, flexural and tensile strengths, ductility, and fracture toughness (Z. Bayasi, R. Bhatacharya, M. Posey, 1989).

2.3 Steel Fibre Reinforced Concrete

2.3.1 General

SFRC can, in general, be produced using conventional concrete practice, though there are obviously some important differences. According to Chanh N. V., the basic problem is to introduce a sufficient volume of uniformly dispersed to achieve the desired improvements in mechanical behaviour, while retaining sufficient workability in the fresh mix to permit proper mixing, placing and finishing. The performance of the hardened concrete is enhanced more by fibres with a higher aspect ratio, since this improves the fibre-matrix bond. On the other hand, a high aspect ratio adversely affects the workability of the fresh mix. In general, the problems of both workability and uniform distribution increase with increasing fibre length and volume.

Steel fibers are short, discrete lengths of steel with an aspect ratio from about 20 to 100, and with any of several cross sections. Some steel fibers have hooked ends to improve resistance to pullout from a cement-based matrix.

Steel fibres shapes are illustrated in Figure 2.1.

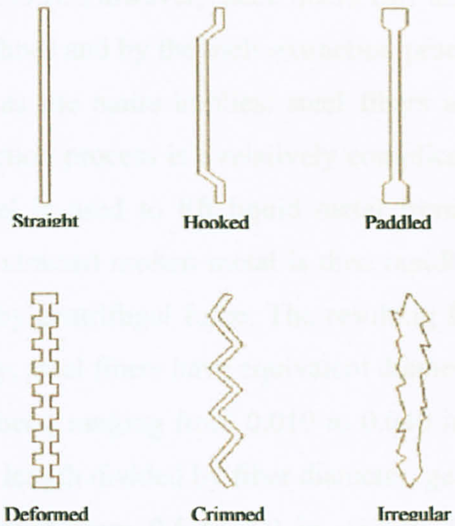


Figure 2.1: *Shapes of Steel Fibre*

ASTM A-820 classifies four different types of fibers based on their manufacture:-

1- *Cold-drawn wire fibers*
   - The most commercially available, manufactured from drawn steel wire
2- *Cut sheet fibers*
   - Manufactured by laterally shearing off steel sheets
3- *Melt-extracted fibers*
   - Manufactured with a relatively complicated technique where a rotating wheel is used to lift liquid metal from a molten metal surface by capillary action.
4- *Other fibers*
   - Manufactured as several in length, diameter, and aspect ratio, as well as minimum tensile strength, and bending requirement

According to Portland Cement Association, early steel fibers used as concrete reinforcement were round and smooth. They were obtained by cutting or chopping wire. Today, smooth, straight fibers have largely been replaced by fibers that have either rough surfaces, hooked ends, or are crimped or undulated throughout their length. These characteristics improve a fiber's resistance to pullout from a cement-based matrix. Most commercially available steel fibers are manufactured from drawn steel wire (Portland Cement Association, 1993). However, steel fibers can also be made from steel sheet material (slit sheet method) and by the melt-extraction process. Slit sheet steel fibers are manufactured exactly as the name implies: steel fibers are literally sheared off steel sheets. The melt-extraction process is a relatively complicated manufacturing technique where a rotating wheel is used to lift liquid metal from a molten metal surface by capillary action. The extracted molten metal is then rapidly frozen into fibers and then thrown off the wheel by centrifugal force. The resulting fibers have a crescent-shaped cross section. Typically, steel fibers have equivalent diameters (based on cross-sectional area for noncircular fibers) ranging from 0.010 to 0.040 in. (0.25 to 1.00 mm). Aspect ratios, defined as fiber length divided by fiber diameter, generally range from 30 to 100. Steel fiber lengths ranged from 0.5 to 3.0 in. (13 to 75 mm) (American Concrete Institute Report, 1996). Use of short steel fibers facilitates mixing and uniform dispersion in freshly mixed concrete.

Normally, carbon steel fibers are used in portland cement-based SFRC. However, various fibers made of corrosion-resistant alloy steels are available. Their use is dictated by cost and exposure conditions. Stainless steel fibers, for example, are used for most high-temperature applications. The yield strengths of commercially available steel fibers vary from 50,000 to as much as 250,000 psi (345 to as much as 1725 MPa). Three different fabrication methods have been successfully used to produce SFRC. They are conventionally mixed SFRC, steel fiber reinforced shotcrete, and slurry-infiltrated fiber concrete (SIFCON).

Plastic shrinkage is a common problem encountered in concrete structure with large surface area. The rapid changes of temperature and humidity lead to the significant water evaporation and may result to the existence of tensile stresses in concrete structure. Cracking will take place when the tensile stresses exceed the tensile strength. The cracks allow the penetration of carbon dioxide, oxygen, and any other aggressive external substances that will contribute to the concrete deterioration.

Steel fiber reinforced concrete undergoes trilinear deformation behaviour as shown in Figure 2.2. Point A on the load-deflection diagram represents the first cracking load or can be classified as first-crack strength. It is the same load level where a non-reinforced concrete element cracks. In other words, the slope OA in the load-deflection diagram is the same for both plain and fiber reinforced concrete.

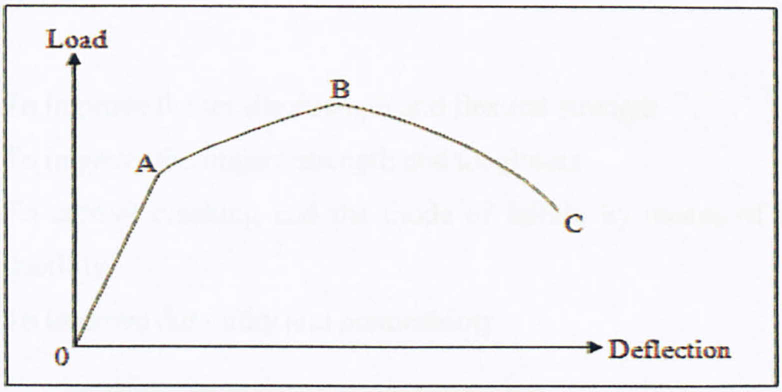


Figure 2.2: *Schematic load-deflection relationship of steel fiber reinforce concrete*

During cracking, the applied load is transferred to the fibers which bridge and tie the crack from opening further. As the fibers deform, additional narrow cracks develop and continued cracking of the matrix takes place until the maximum load reaches point B of the load-deflection diagram. In this stage, debonding and pullout of some of the fibers occur. However, the yield strength of most of the fibers is not reached.

For the slope BC of the load-deflection diagram, matrix cracking and fiber pullout continue. The fibers may fail by yielding or by fracturing of the fibers if the fibers are long enough to be able to maintain their bond with the surrounding gel depending on their size and spacing.

2.3.2 Properties of SFRC

The concept of reinforcing brittle building materials with various forms of fiber has been known since a long time ago. Nowadays, fiber reinforced concrete has been widely used such as at the airport runways, slabs on grade, shotcrete for slope and tunnel stabilisation, pre-cast concrete products, coastal structures, machine foundations, defence shelter, etc. It has been reported that 150,000 metric tonnes is used worldwide annually. The most common fiber used is steel fibers. The main objectives of modern engineers in attempting to modify the properties of concrete by the inclusion of steel fibers are as follows:

- To improve the tensile strength and flexural strength
- To improve the impact strength and toughness
- To control cracking and the mode of failure by means of post-cracking ductility
- To improve durability and permeability

Figure 2.3: Steel Fibre

Mechanical properties of steel fiber reinforced concrete are influenced by a number of variables. These include type and percentage of fiber addition, aspect ratio of the fiber, strength of the matrix, and size of the aggregate. The available data have been developed over many years by a large number of researchers for a range of variables.

Therefore, the data are best presented as trends or ranges rather than absolute values. Bond between matrix and fiber will be increased as the length of the fiber increases. Thus, the longer of fiber will give the greater of strength of the composite. It would be desirable to have a fiber length sufficient to induce enough stress in the fiber for a tensile failure to occur. This is usually not possible since fibers with aspect ratios greater than 100 are difficult to disperse uniformly and result in non workable concrete mixes. Thus, most mixes use fibers with aspect ratios of 100 or less (Timuran Engineering Sdn. Bhd.).

Care must be taken in the mixing procedures. Most commonly, when using a transit mix truck or revolving drum mixer, the fibres should be added last to the wet concrete. The concrete alone, typically, should have a slump of 50-75 mm greater than the desired slump of the SFRC (Chanh N. V). Of course, the fibres should be added free of clumps, usually by first passing them through an appropriate screen. Once the fibres are all in the mixer, about 30-40 revolutions at mixing speed should properly disperse the fibres. Alternatively, the fibres may be added to the fine aggregate on a conveyor belt during the addition of aggregate to the concrete mix. The use of collated fibres held together by a water-soluble sizing which dissolves during mixing largely eliminates the problem of clumping.

SFRC can be placed adequately using normal concrete equipment. It appears to be very stiff because the fibres tend to inhibit flow; however when vibrated, the material will flow readily into the forms. It should be noted that water should be added to SFRC mixes to improve the workability only with great care, since above a w/c of about 0.5, additional water may increase the slump of the SFRC without increasing its workability and place ability under vibration. The finishing operations with SFRC are essentially the same as for ordinary concrete, though perhaps more care must be taken regarding workmanship.

2.3.2.1 Mechanical Properties of Fresh Steel Fibre Reinforced Concrete

Achieving adequate workability is one of the problems generated when using steel fibre reinforced concrete. The inclusion of the fibres into the concrete mix influences its workability, with increasing in the steel fibre volume and aspect ratio leading to decreased workability. The ACI Committee report in 1996, reported that in the typical ranges of volume fractions used for steel fibre reinforced concrete (0.25 to 1.5 volume percent), the addition of steel fibres may reduce the measured slump of the composite as compared to plain concrete in the range of 25 to 102mm. In addition to the above consideration the balling of fibres must be avoided.

2.3.2.2 Mechanical Properties of Hardened Steel Fibre Reinforced Concrete

The most significant consequence of fibre addition to concrete is the delay and control of tensile cracking in the composite material. Through intercept micro-cracks, many of the mechanical properties of the composite are improved. The level of improvement achieved, compared to plain concrete, depends on the dosage rate and type of fibre (ACIFC, 1999).

2.3.3 Proportion of SFRC

Most steel fiber reinforced concrete is mixed in conventional concrete mixers and placed and consolidated by conventional means. Fiber contents used generally range from 0.0% to 2.0% by volume. However, Grzybowski and Shah found that steel fiber contents as low as 0.25% by volume substantially reduced the width of cracks resulting from restrained drying shrinkage. Optimum fiber contents depend greatly on the quantities and characteristics of the concrete mix constituents (water-cement ratio, aggregate shape, aggregate gradation, etc.) and the characteristics of the fiber itself (aspect ratio, cross-sectional configuration, strength, etc.).

Steel fiber contents in excess of 2% generally result in poor workability and fiber dispersion. The largest use for conventionally mixed SFRC has been in airport pavements, both as overlays to repair existing pavement and in new construction. Design criteria have been developed for both applications. Also, a number of experimental highway and bridge deck applications have been undertaken with considerable success. Another application that has shown considerable potential is conventionally mixed SFRC for industrial floors. Such floors frequently must withstand potentially damaging concentrated and dynamic loads from steel wheels, tank or tractor treads, or falling objects. For this type of application, SFRC has been used as the heavy-duty topping of a two-course floor, a full-depth floor, or an overlay on an existing floor. Conventionally mixed SFRC has been used in hydraulic structures— spillways, sluiceways, and stilling basins—to enhance the resistance to cavitation and erosion damage caused by high-velocity water flow. Laboratory tests and field applications have shown that SFRC will last about three times longer than plain concrete subjected to high-velocity water flow.

Procedures for designing conventional steel fibre concrete mixes are essentially the same as those for plain concrete. However, certain precautions must be taken to assure uniform dispersion of fibers, to prevent segregation or clumping of fibers during mixing, and to obtain a workable mix capable of being properly placed, consolidated, and finished.

The mix variables for conventional steel fibre reinforced concrete generally fall within certain ranges depend upon requirements for a particular job, in terms of strength, workability, and so on. Several procedures for proportioning SFRC mixes are available, which emphasize the workability of the resulting mix. However, there are some considerations that are particular to SFRC.

Here, the range of proportions for normal weight SFRC is shown in Table 2.2.

Property	Mortar	9.5mm Max Aggregate Size	19mm Max Aggregate Size
Cement (kg/m^3)	415-710	355-590	300-535
W/C	0.3-0.45	0.35-0.45	0.4-0.5
Fine/Coarse Aggregates (%)	100	45-60	45-55
Entrained Air (%)	7-10	4-7	4-6
Fibre Content (%) by Volume:-			
smooth steel	1-2	0.9-1.8	0.8-1.6
deformed steel	0.5-1.0	0.4-0.9	0.3-0.8

Table 2.2: Range of proportions for normal weight of SFRC

A particular fibre type, orientation and percentage of fibers, the workability of the mix decreased as the size and quantity of aggregate particles greater than 5 mm increased; the presence of aggregate particles less than 5 mm in size had little effect on the compacting characteristics of the mix. Figure 2.4 shows the effects of maximum aggregate size on workability.

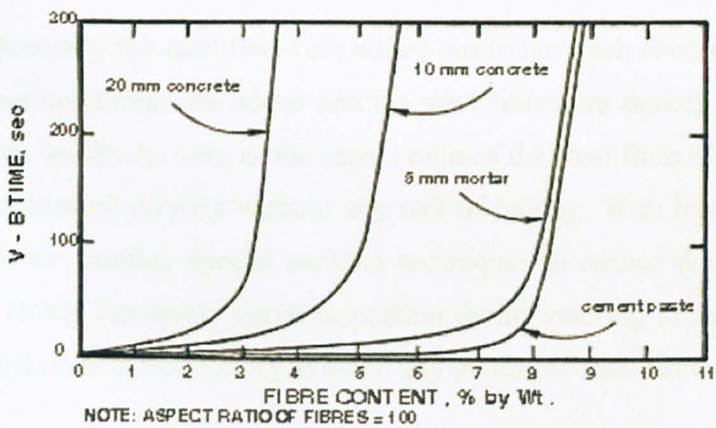


Figure 2.4: Workability vs. fibre content for matrices with different maximum aggregate sizes

The second factor which has a major effect on workability is the aspect ratio (*l/d*) of the fibres. The workability decreases with increasing aspect ratio, as shown in Figure 2.5, in practice it is very difficult to achieve a uniform mix if the aspect ratio is greater than about 100.

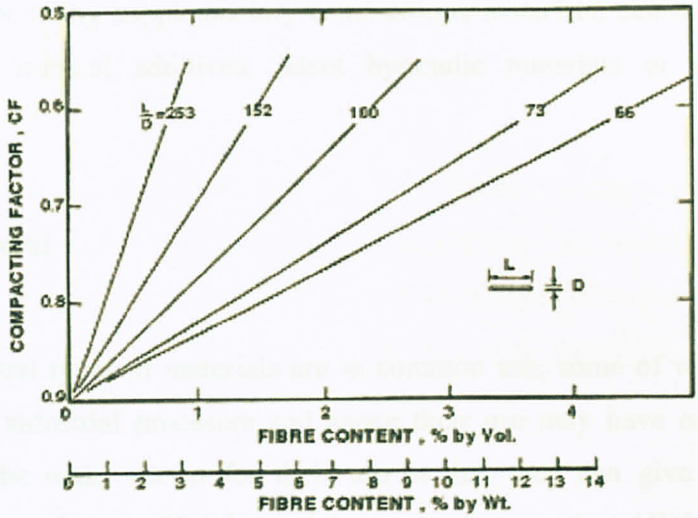


***Figure 2.5:** Effect of fibre aspect ratio on the workability of concrete as measured by the compacting factor*

2.3.4 Addition and Mixing (Steel Fibre)

Generally the steel fibres are added last to the fresh concrete, care being taken to ensure that no clumps are added and the steel fibres are rapidly moved from the entry point to the mixer. As long as the aspect ratio of the steel fibre is less than 50, the fibres may be dispensed directly without any risk of balling. With higher aspect ratios some manufacturers employ special packing techniques to reduce the risk (ACI Committee 544.1R, 1996). However, visual inspection during pouring is necessary to check steel fibre distribution is satisfactory to avoid any balling of steel fibres.

2.4 Cement Replacement Material

Cement replacement materials are used as a substitute for some of the Portland cement in a concrete; partial cement replacement materials is therefore a more accurate but less convenient name. Confusingly, there are also a number of other names for this group of materials, including supplementary cementitious materials, cement extenders, mineral admixtures, mineral additives, latent hydraulic materials or simply cementitious materials.

2.4.1 General

Several types of materials are in common use, some of which are by-products from other industrial processes and hence their use may have economic advantages. However, the main reason for their use is that they can give a variety of useful enhancements of or modifications to the concrete properties. All the materials have two (2) common features:-

- Their particle size range is similar to or smaller than Portland cement
- They become involved in the hydration reactions

According to Ping Kun Chang (2003), to achieve high strength and workability while reducing creep and shrinkage and low durability, it is suggested to use water-reducing agent, superplasticizers and pozzolanic materials in the mix designs. The chemical reactivity of superplasticizers lasts only for 60 min. While pozzolanic materials, such as fly ash, blast-furnace slag or rice husk ash, are used, there is a risk of insufficient early strength of concrete. Therefore, how to minimize or eliminate the adverse effects of the materials used in the mixture design to increase durability is the main focus of the research.

Pozzolanic materials are crucial to HPC as far as flowability is concerned. In addition to lowering the heat of hydration, the use of fly ash and slag can improve the workability, plasticity, water tightness, resistance to sulfate and seawater attack. The mixture design of HPC emphasizes the amount of binder used. A higher content of pozzolanic materials implies that less cement is needed. Controlling the water content and the water-to-solid ratio (W/S) is an indirect approach to stabilizing the volume, thus ensuring greater durability achieved in the mixture proportion of concrete.

2.4.2 Rice Hush Ash (RHA)

Rice Husk Ash (RHA) is an agricultural waste, constitutes about one fifth of the 500million metric tons of rice produced annually in the world. Due to the growing environmental concern and the need to conserve energy and resources, efforts have been made to burn the husks at controlled temperature and atmosphere and to utilize the ash as a building material.

2.4.2.1 General

RHA is a very pozzolanic material, which used in order to reduce cost and at the same time maintain or improve the concrete properties, and its particle size and specific surface depend upon the burning conditions under which it is produced. In general, the average particle size ranges from 5 to 10 urn, and the specific surface area ranges from 20 to 50 m^3/g. A previous investigation indicated that the RHA used in this study is highly pozzolanic, and can be used as a supplementary cementing material to produce high performance concrete.

The ash produced after the husks have been burned, (abbreviated to RHA), is high in silica. A number of possible uses are being investigated for this. These uses include:

- aggregates and fillers for concrete and board production

- economical substitute for microsilica / silica fumes
- absorbents for oils and chemicals
- as insulation powder in steel mills
- as a release agent in the ceramics industry

Microwave Incinerator Rice Hush Ash (MIRHA) is a processed waste material incinerated using microwave. In other word, MIRHA is one of a product of RHA since it also used processed from waste material.

2.4.2.2 Properties of RHA

Research by Nuruddin M. F., Syafiq N., Kamal N. L. M. showed that RHA can be a green material and re-utilized in construction materials, by controlling the burning temperature to ensure it is in a non-crystalline state. It has been reported that RHA can be added to concrete mixtures to substitute the more expensive Portland cement to lower the construction cost while at the same time protecting the environment. Its also cites that RHA is not only cheap but also can improve the durability of concrete (Coutinho J. S., 2003). Some researchers found that through pozzolanic reaction, the addition of pozzolanic materials can affect the porosity of concrete by strengthening the aggregate-cement paste and the reaction can modify the micropores structure. The products formed due to the pozzolanic reactions occupy the empty spaces in concrete pore structures which thus become densified. The porosity of cement paste is then reduced, and subsequently the pores are refined.

2.4.2.2.1 Physical Properties of RHA

Ristiana D. P. stated that the RHA physical characteristic can be identified by using X-Ray Diffractometer (XRD) for the structure, Surface Area Analyser for porosity, Analyser Activation Acelerator Neutron for percentage silica and Fourier Transformation Infra Red for functional group in the RHA.

The physical properties of RHA are detailed in Table 2.3 below:-

Physical Properties	Description
Density (kg/m^3)	805.6
Specific Gravity	2.06
Particle Size (nm)	17.2
Fineness:	
• Passing 45 μm(%)	99.0
• Nitrogen Adsorption(m^2/g)	38.9

***Table 2.3**: Physical Properties of RHA*

2.4.2.2.2 Chemical Properties of RHA

Rice Husk Ash (RHA) contains a carbon content of 5.91% and is black in colour. This is because RHA highly contain of silica by mass (about 85% to 90%). Chemical analysis indicates that the material is principally composed of SiO_2 (87.2%) and is also high in loss on ignition (8.55%). The ash contains a relatively high potassium content which originates mainly from the soil or due to the use of fertilizers.

The overall chemical properties of RHA are detailed in **Table 2.4** below:-

Chemical Properties	Percentage (%)
Silicon Dioxide (SiO_2)	87.2
Loss on ignition	8.55
Carbon (C)	5.91
Potassium Oxide (K_2O)	3.68
Sodium Oxide (Na_2O)	1.12
Calcium Oxide (CaO)	0.55
Phosphorus Oxide (P_2O_3)	0.50
Chlorides (Cl)	0.45
Magnesium Oxide (MgO)	0.35
Sulphur Oxide (SO_3)	0.24
Ferric Oxide (Fe_2O_3)	0.16
Aluminum Oxide (Al_2O_3)	0.15
Titanium Oxide (TiO_2)	0.01

***Table 2.4**: Chemical Properties of RHA*

CHAPTER 3

METHODOLOGY

3.1 General

The experimental program was planned to investigate the effect of steel fibre and MIRHA in the concrete. The concrete strengths, which will be investigated include 25 MPa for normal-strength, 50 MPa for medium-strength, and 70 MPa representing high-strength of concrete. The steel fiber volume percentage content ranges from 0 to 0.8% of the concrete matrix. This project will also study the influence of introducing MIRHA to plain concrete and also steel fiber concrete.

Table 3.1 show the lists of specimen used for this study:-

Types of Specimen	Grade of Concrete	Proportion
Plain Concrete	G 25, G 50, G70	(as control sample)
Plain Concrete + Steel Fibre	G 25, G 50, G70	Steel Fibre → 0.0%, 0.5%, 0.8%, 1.0%
Plain Concrete + Steel Fibre + MIRHA	G 25, G 50, G70	MIRHA → 5%

Table 3.1: *Types of Specimen*

3.2 Material

The materials used include:-

3.2.1 Cement

Cement is a powder, which by hydraulic reaction forms a solid, cohesive mass. Ordinary Portland Cement (OPC), which is the standard, grey cement used for most purposes. Ordinary Portland cement sets by hydraulic reaction. It is a complex mixture of components, probably the most important of which are dicalcium and tricalcium silicates (C2S and C3S to cement chemists). Besides that it also contains tricalcium silicate and tetracalcium aluminoferrite.

Type I Portland Cement produced by local company was used. The cement complied with the specification requirements of ASTM C150. The overall chemical properties of OPC are detailed in **Table 3.2** below:-

Chemical Properties	Percentage (%)
Silicon Dioxide (SiO_2)	21.20
Loss on ignition	4.00
Calcium Oxide (CaO)	65.0
Magnesium Oxide (MgO)	0.70
Sulphur Oxide (SO_3)	1.50
Ferric Oxide (Fe_2O_3)	3.50
Aluminum Oxide (Al_2O_3)	6.00
Free Lime	2.00
IR	1.50

Table 3.2: *Amount of chemical constituents in OPC*

3.2.2 Steel Fibre

In this study, the hooked end and short steel fibers produced by local company, Timuran Engineering Sdn. Bhd. located at Batu Gajah, Perak were used.

The steel fibers had a tensile strength of 1200 MPa. They are known by the trade name (Dramix ZP305) with a length (L) of 30 mm and diameter (d) is 0.55 mm giving an aspect ratio of L/d =55. Figures 3.2 and 3.3 shown typical form of the steel fibre as imported (before introducing into the concrete) and as used in the mix. The steel fibre volume fractions were used in this study: 0, 0.3, 0.5 and 0.8% by volume of the concrete mix.

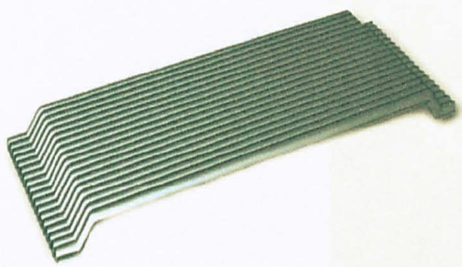


Figure 3.1: *Steel Fibres as imported from the Company*

Figure 3.2: *Steel Fibres as used in the mix*

3.2.3 MIRHA

Microwave Incinerator Rice Hush Ash (MIRHA) is a processed waste material, Rice Husk Ash (RHA) incinerated using microwave. RHA was burn and ground before used as additive in the mixing. To produce the best pozzolanas, the burning of RHA must be carefully controlled to keep the temperature below 700°C and supplied an adequate quality of air so that we can get the ash of it which is free from activated carbon. Then, it will be grind using the ball or hammer mills so that we can get the finer powder or RHA.

Figure 3.3: *Microwave Incinerator*

Figure 3.4: *Grinding Process*

3.3 Sample Preparation

Before doing the mixing, preparation of the material is very important and it must be done before the mix's day to avoid any error or difficulty doing the mixing.

3.3.1 Flow Chart of Sample Preparation

The sample preparation procedure was divided into several phases:

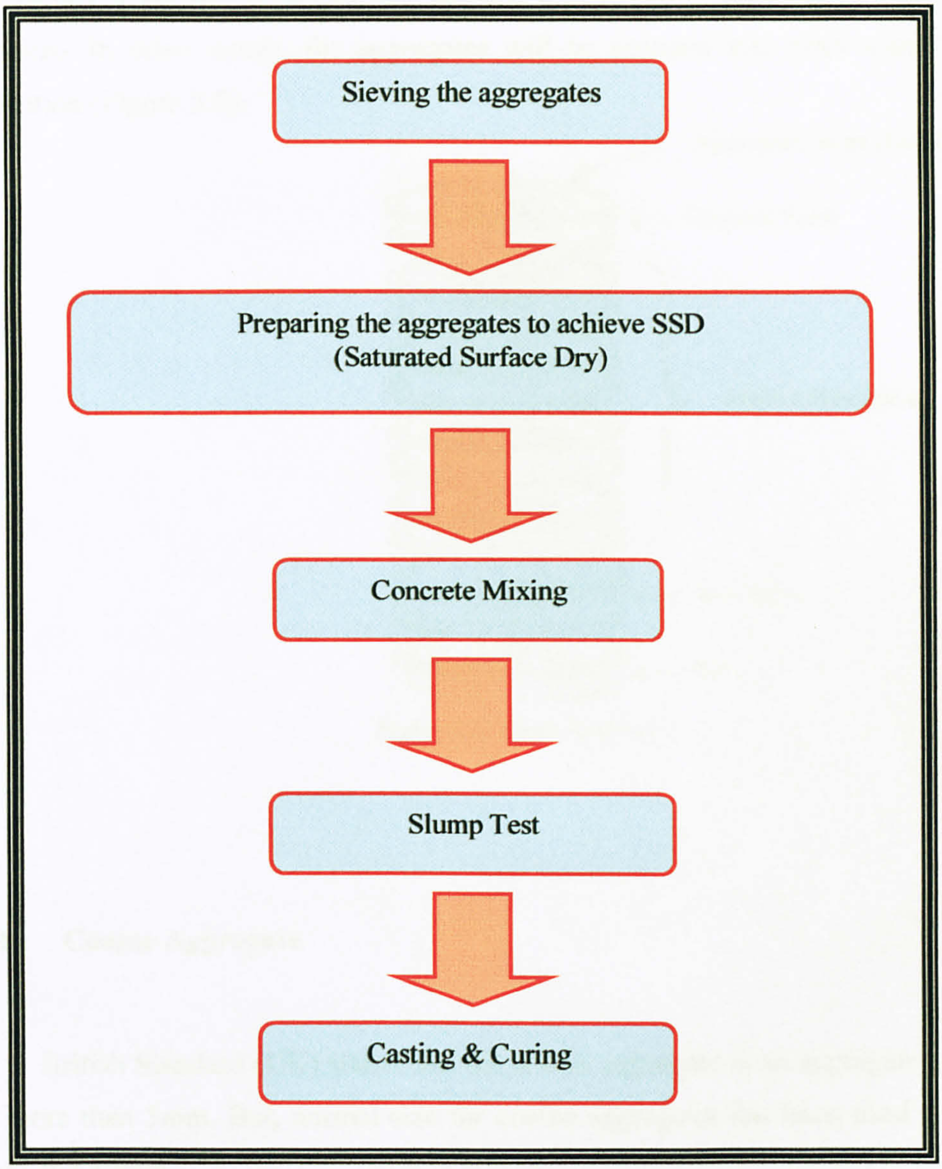


Figure 3.5: *Flow Chart of Methodology*

3.3.2 Sieve Analysis

The sieve analysis is a process which to obtain the distribution of particle sizes by screening a known weight of soil through a stack of sieves of progressively finer mesh size. In other words, the aggregates will be grouped into sizes using the size distribution (Figure 3.6).

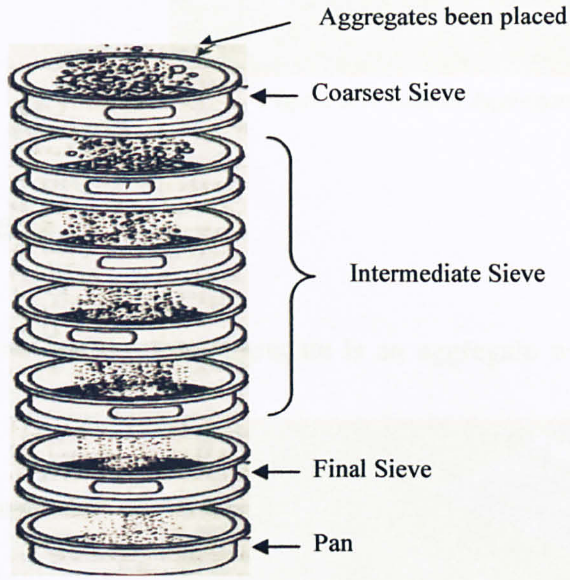


Figure 3.6: Sieve Analysis

3.3.2.1 Coarse Aggregate

British Standard (UK) stated that the coarse aggregate is an aggregate which has size more than 5mm. But, normal size for coarse aggregates has been used are 10mm, 20mm and 40mm.

1. The aggregates were filled into the sieving pan with 19mm holes. The coarse aggregate are shown in **Figure 3.7.**

2. The sieving process continues for 5 minutes.
3. All aggregates that pass the sieve are taken for making the specimens.

Figure 3.7: Coarse Aggregates

3.3.2.2 Fine Aggregate

British Standard (UK) stated that the fine aggregate is an aggregate which has size less than 5mm.

1. The fine aggregate (**Figure 3.8**) is dried in room temperature.
2. Sieving pan of 2mm holes is used to sieve the fine aggregate.
3. All aggregates that pass the sieve are taken for making the specimens.

Figure 3.8: Fine Aggregates

3.3.3 Preparing SSD

1. The aggregates are rinsed with clean water to remove lumps and coatings on particles.
2. The aggregates are soaked in water for 24 ± 2 hours.
3. The aggregates are then rewashed to remove slaked material.

4. After rewashing, the aggregates are left in room temperature as shown in **Figure 3.9** for several hours until the surface of the aggregates are dry.

Figure 3.9: *SSD Aggregates*

3.3.4 Concrete mixing

All concrete should be mix thoroughly until it is uniform. The sequence of concrete mix is very important and it must be followed accordingly. The procedure of concrete mix incorporating with steel fibre and MIRHA is shown below:

1. Pour all coarse and fine aggregates into the mixer and mix for 25 seconds to ensure uniform distribution between both materials.
2. Pour half of the water and mix for 1 minute.
3. Leave the mixes for 8 minutes to let both coarse and fine aggregates to absorb water.
4. Pour all Portland cement into the mixer and mix for 1 minute.
5. Pour another half of the water and mix for 3 minutes.
6. Pour steel fibre uniformly and mix for 2 minute.
7. Finally perform hand mixing until the mix is in uniform stage.

3.3.5 Casting & Curing

Casting is a manufacturing process by which a liquid material (fresh concrete) is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting.

Curing is the process of keeping concrete under a specific environmental condition until hydration is relatively complete. Because the cement used in concrete requires time to fully hydrate before it acquires strength and hardness, concrete must be cured once it has been placed.

1. The moulds (**Figure 3.10**) and its base are clamped together during casting to prevent leakage of mortar.
2. The fresh concrete mix is casted by using 100x100x100 casting moulds.
3. Before assembling the moulds, its mating surface is covered with oil to prevent the development of bond between the mould and the concrete.
4. Each mould is filled with in 3 layers. Each layer is compacted by a vibrating hammer or using a vibrating table or by not fewer than 35 strokes of a 25mm square steel punner.
5. The cube samples are stored undisturbed for 24 hours at room temperature.
6. Then, the samples are stripped from the moulds and put in the water for further curing.

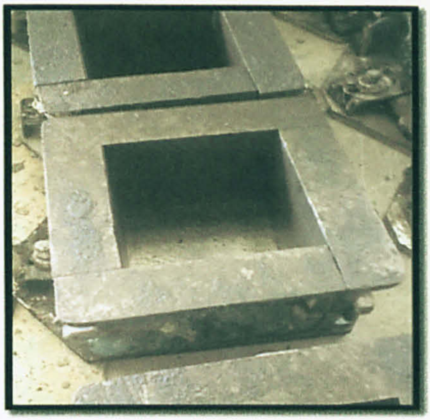


Figure 3.10: *Moulds covered with oil*

Figure 3.11: *Concrete filled moulds*

3.4 Testing

According to Portland Cement Association in March 1993, there are various experimental tests have been conducted on determining the strength characteristics of concrete. Concrete is tested to ensure that the material that was specified and bought is the same material delivered to the job site. There are a dozen different test methods for freshly mixed concrete and at least another dozen tests for hardened concrete. For this project, there are several tests were selected to determine the strength characteristic of the concrete after introducing the steel fibre and also MIRHA, based on the early objective of the study, as listed below:

3.4.1 Fresh Concrete Test

The purpose of this fresh concrete test was to measure the workability of the concrete.

3.4.1.1 Slump Test

The slump flow test used to assess the horizontal free flow of concrete in the absence of obstructions. It gave no indication of the ability of the concrete to pass between reinforcement without blocking, but some indication of resistance to segregation. The equipments included a truncated cone with the internal dimension of 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm with a base plate of a stiff non-absorbing material.

1. The mould is moisturized with water.
2. The mould is placed on a smooth surface with a smaller opening at the top.
3. The mould is then filled with concrete in 3 layers. Each layer is tamped 35 times with a standard 16mm (5/8 inch) diameter steel rod, rounded at the end, and the top surface is struck off.

4. After filling, the cone is immediately lifted slowly. The decrease in the height of the slumped concrete is called slump, and is measured to the nearest 5mm (the decrease is measured to the highest point according to BS 1881:Part 102:1983)

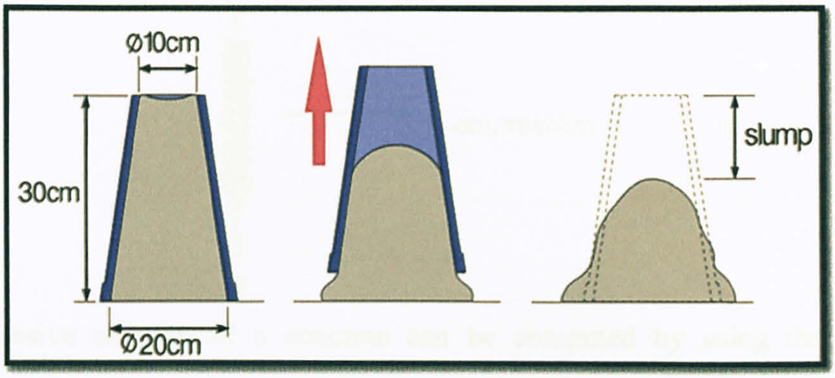


Figure 3.12: Slump Test Illustrations

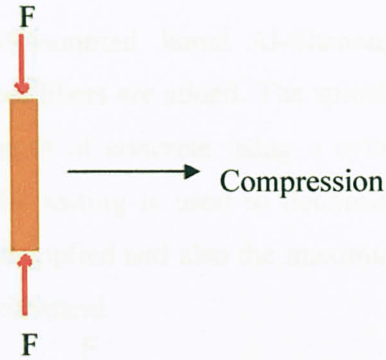
3.4.2 Hardened Concrete Test

The hardened concrete tests have been conducted to measure the characteristics of the concrete.

3.4.2.1 Compressive Test

According to American Concrete Institute Report on Fibre Reinforced Concrete (1996), the compressive strength of concrete is little influenced by additional of steel fiber with observed increases ranging from 0 to 15 percent for up to 1.5 volume percent of fibers. But, it is mainly controlled by the concrete matrix design.

Compressive strength is the capacity of a material to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed. The compressive strength is usually obtained experimentally by means of a compressive test. The apparatus used for this experiment is the same as that used in a tensile test. However, rather than applying a uniaxial tensile load, a uniaxial compressive load is applied.



The compressive strength of a concrete can be computed by using the following formula:

$$\boxed{\Phi \equiv \frac{F}{A}}$$

Where;

σ = Compressive Strength (stress), kN/m^2

F = Axial Force (load) at the time of failure, kN

A = Area, m^2

This test was performed on 150 x 150 x 150mm cube specimens. This compressive strength tests was conducted with 6.80kN/s of pace rate and consists of applying a compressive axial load to sample at a continuous rate without shock and within a prescribed range until failure occurs, as shown in **Fig. XX.**

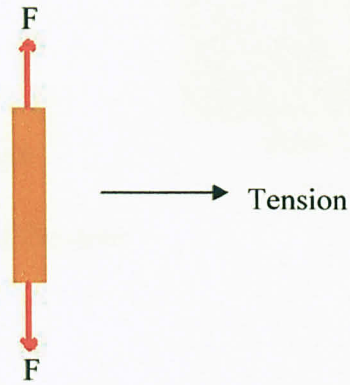
1. The cube, while still wet, is placed in the compression tester (**Figure 3.13**) with the cast faces in contact with the platens of the testing machine.
2. The load on cube is applied at a constant rate of stress equal to 6.80kN/s until it fails.

***Figure 3.13:** Compression Test*

The maximum load before the cube fails is taken and the compressive strength is calculated by dividing the maximum load to the cross-sectional area of the cube.

3.4.2.2 Splitting Tensile Test

According to Dr. Mohammad Jamal Al-Shannag, the tensile strength will increase after cracking, if steel fibers are added. The splitting tensile test is a method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. This tensile testing is used to determine the behavior of a sample while an axial stretching load applied and also the maximum load (tensile strength) that a material or a product can withstand.



The splitting tensile strength of a concrete cylinder can be computed by using the following formula:

$$\boxed{T \equiv \frac{2xF}{\Pi x L x d}}$$

Where;

T = Splitting Tensile Strength

P = Axial Force (load) at the time of failure

L = Length of the cylindrical specimen

d = Diameter of the specimen

This test was performed on 100 x 200 mm cylinder specimens with 0.94kN/s of pace rate. According to the splitting tensile strength test described in ASTM, a vertical uniform line load is applied to the specimen to produce 26 horizontal tensile stresses along the mid section on vertical axis, as shown in **Figure 3.14.**

1. The specimen is placed in specimen holder with the cast faces in contact with the steel rod at both top and bottom of the specimen.
2. The load on cube is applied at a constant rate of stress equal to 0. 94kN/s until it fails.
3. The maximum load before the cube fails is taken and the tensile strength is calculated by using the following equation:

$$\frac{2P}{\pi a^2}$$

Figure 3.14: Splitting Tensile Test

Where; P = the maximum load

a = the side length of the cube

3.4.2.3 Porosity Test

Porosity of concrete is an important factor as classifying its durability. Generally, concrete of a low porosity will afford better protection to reinforcement within it that concrete of high porosity. Porosity can be measured by vacuum saturation of a concrete specimen, measuring its weight gain and expressing this as a percentage of the mass of the sample.

In this research, the comparative performance of hardened concrete is investigated by comparing the development of porosity between each percentage of steel fibre and also with MIRHA. Porosity is a measure of the void spaces in a material.

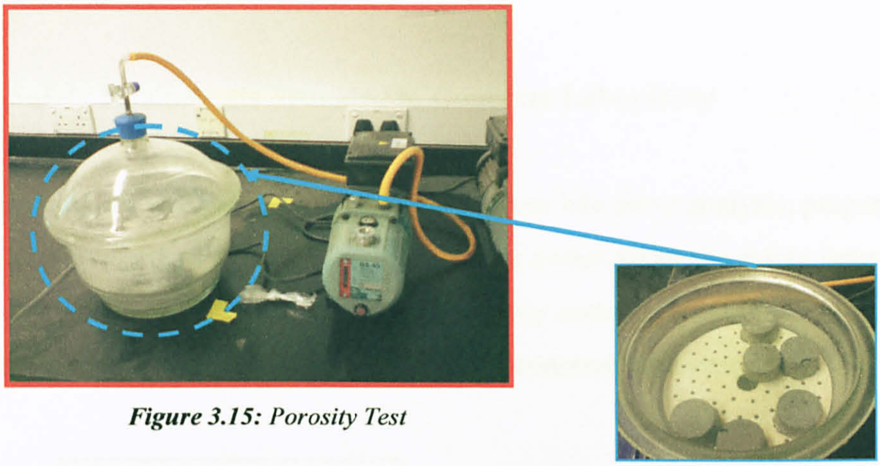


Figure 3.15: Porosity Test

3.5 HSE Requirements

3.5.1 Safety Equipments Provided in Concrete Laboratory

All the laboratory works for the concreting process like sieve analysis, preparing the aggregates, concrete mixing, testing, etc. need to aware about the safety issues. This is because any incidents can be occurred without any noticed. The following figures are the safety equipments that have provided in the concrete laboratory:

Figure 3.16: *Safety Equipment*

3.5.2 HSE Analysis

EQUIPMENT	ACTIVITY	HAZARDS	SAFE PROCEDURE
Sieving Machine	Switching the machine Sieving aggregates	Electricity Shock Hearing Hazard	Wear gloves & rubber shoes Wear earmuff
Concrete Mixer	Switching the machine Mixing concrete	Electricity Shock Body Injuries	Wear gloves & rubber shoes Always close the container during the mixing process
Compression & Tensile Machine	Switching the machine Conducting tests	Electricity Shock Body Injuries	Wear gloves & rubber shoes Isolate the testing zone by closing the gate of the machine
Vibrator	Switching the machine Vibrating the matrix	Electricity Shock Electricity Shock	Wear gloves & rubber shoes Wear gloves & rubber shoes
Cement	Handling the cement	Harmful to lung if inhaled	Wear dust mask

Table 3.3: *HSE Analysis*

CHAPTER 4

RESULT AND DISCUSSION

This chapter consists of two major parts: the first one deals with the effect of steel fibre on the characteristic of concrete; whereas the second one deals with the effect of MIRHA on the characteristics of concrete. For further investigation of this study, all the data will be gathered and analyzed to determine the optimum proportion of steel fibre.

4.1 Mix Design

As with any other type of concrete, the mix proportions for conventional concrete and also SFRC depend upon the requirements for a particular job, in terms of strength, workability, and so on.

Basically, there are three (3) types of characteristic strength, which are:-

- 25 N/mm^2 at 28 days → consider as low strength of concrete
- 50 N/mm^2 at 28 days → consider as medium strength of concrete
- 70 N/mm^2 at 28 days → consider as high strength of concrete

The following requirement are also specified and thus entered under relevant item on the mix design form:-

- Cement Type : Ordinary Portland Cement
- Slump required : 60 – 180mm
- Maximum Aggregate : 20mm
- Proportion defective : 5 percent

****Note:-*** *When specifying the characteristic strength required, the permitted percentage of defectives must be known and this is then stated as the required value in Item 1.1 (mix design) so that the appropriate constant k can be used in Item 1.3 (mix design).*

4.1.1 Plain Concrete (Control)

4.1.1.1 Concrete Grade 25

The design data is presented in the following table.

Table 4.1: Concrete Mix Design for Grade 25

Stage	Item		Reference or Calculation	Values
1	1.1	Characteristic Strength	Specified	25 N/mm2 at 28 days Proportion defective 5%
	1.2	Stardanrd Deviation	Fig. 3	8 N/mm2
	1.3	Margin	C1	(k = 1.64) 1.64 x 8 = 13.12 N/mm2
	1.4	Target Mean Strength	C2	25 + 13.12 = 38.12 N/mm2
	1.5	Cement Type	Specified	OPC
		Aggregate Type : Coarse		Crushed
	1.6	Aggregate Type : Fine		Uncrushed
	1.7	Free-Water/Cement ratio	Table 2, Fig. 4	0.58
	1.8	Maximum Free-Water/Cement ratio	Specified	-
2	2.1	Slump	Specified	60-180mm
	2.2	Maximum Aggregate Size	Specified	20mm
	2.3	Free-Water Content	Table 3	210 kg/m³
3	3.1	Cement Content	C3	210 / 0.58 = 362.1 kg/m³
	3.2	Maximum Cement Content	Specified	-
	3.3	Minimum Cement Content	Specified	-
	3.4	Modified Free-Water/Cement ratio		-
4	4.1	Relative Density of Aggregate (SSD)		2.6 (assumed)
	4.2	ConcreteDensity	Fig. 5	2400 kg/m³
	4.3	Total Aggregate Content	C4	2400 - 362.1 - 210 = 1827.9 kg/m³
5	5.1	Grading of Fine Aggregate	BS 882	Zone 4
	5.2	Proportion of Fine Aggregate	Fig. 6	28%
	5.3	Fine Aggregate Content	C5	1827.9 x 0.28 = 511.8 kg/m³
	5.4	Coarse Aggregate Content		1827.9 - 520.2 = 1016.1 kg/m³

Quantities	Cement (kg)	Water (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
per m³	362.1	210	511.8	1016.1

4.1.1.2 Concrete Grade 50

The design data is presented in the following table.

Table 4.2: Concrete Mix Design for Grade 50

Stage	Item		Reference or Calculation	Values
1	1.1	Characteristic Strength	Specified	50 N/mm2 at 28 days Proportion defective 5%
	1.2	Stardanrd Deviation	Fig. 3	8 N/mm2
	1.3	Margin	C1	(k = 1.64) 1.64 x 8 = 13.12 N/mm2
	1.4	Target Mean Strength	C2	50 + 13.12 = 63.12 N/mm2
	1.5	Cement Type	Specified	OPC
		Aggregate Type : Coarse		Crushed
	1.6	Aggregate Type : Fine		Uncrushed
	1.7	Free-Water/Cement ratio	Table 2, Fig. 4	0.39
	1.8	Maximum Free-Water/Cement ratio	Specified	-
2	2.1	Slump	Specified	60-180mm
	2.2	Maximum Aggregate Size	Specified	20mm
	2.3	Free-Water Content	Table 3	210 kg/m³
3	3.1	Cement Content	C3	210 / 0.39 = 538.5 kg/m³
	3.2	Maximum Cement Content	Specified	-
	3.3	Minimum Cement Content	Specified	-
	3.4	Modified Free-Water/Cement ratio		-
4	4.1	Relative Density of Aggregate (SSD)		2.6 (assumed)
	4.2	ConcreteDensity	Fig. 5	2400 kg/m³
	4.3	Total Aggregate Content	C4	2400 - 538.5 - 210 = 1651.5 kg/m³
5	5.1	Grading of Fine Aggregate	BS 882	Zone 4
	5.2	Proportion of Fine Aggregate	Fig. 6	25.50%
	5.3	Fine Aggregate Content	C5	1651.5 x 0.255 = 421.1 kg/m³
	5.4	Coarse Aggregate Content		1651.5 - 421.1 = 1230.4 kg/m³

Quantities	Cement (kg)	Water (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
per m³	538.5	210	421.1	1230.4

4.1.1.3 Concrete Grade 70

The design data is presented in the following table.

Table 4.3: Concrete Mix Design for Grade 70

Stage	Item		Reference or Calculation	Values
1	1.1	Characteristic Strength	Specified	70 N/mm2 at 28 days Proportion defective 5%
	1.2	Stardanrd Deviation	Fig. 3	8 N/mm2
	1.3	Margin	C1	(k = 1.64) 1.64 x 8 = 13.12 N/mm2
	1.4	Target Mean Strength	C2	70 + 13.12 = 83.12 N/mm2
	1.5	Cement Type	Specified	OPC
	1.6	Aggregate Type : Coarse		Crushed
		Aggregate Type : Fine		Uncrushed
	1.7	Free-Water/Cement ratio	Table 2, Fig. 4	0.3
	1.8	Maximum Free-Water/Cement ratio	Specified	-
2	2.1	Slump	Specified	60-180mm
	2.2	Maximum Aggregate Size	Specified	20mm
	2.3	Free-Water Content	Table 3	210 kg/m³
3	3.1	Cement Content	C3	210 / 0.3 = 700 kg/m³
	3.2	Maximum Cement Content	Specified	-
	3.3	Minimum Cement Content	Specified	-
	3.4	Modified Free-Water/Cement ratio		-
4	4.1	Relative Density of Aggregate (SSD)		2.6 (assumed)
	4.2	ConcreteDensity	Fig. 5	2400 kg/m³
	4.3	Total Aggregate Content	C4	2400 - 700 - 210 = 1490 kg/m³
5	5.1	Grading of Fine Aggregate	BS 882	Zone 4
	5.2	Proportion of Fine Aggregate	Fig. 6	24%
	5.3	Fine Aggregate Content	C5	1490 x 0.24 = 357.6 kg/m³
	5.4	Coarse Aggregate Content		1490 - 357.6 = 1132.4 kg/m³

Quantities	Cement (kg)	Water (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
per m³	700	210	357.6	1132.4

4.1.2 Plain Concrete with MIRHA and Steel Fibre

Several procedures for proportioning SFRC mixes are available, which emphasize the workability of the resulting mix. However, there are some considerations that are particular to SFRC. As mentioned earlier, there are four (4) types of specimen need to be prepared for this project, follow:-

- Plain Concrete as Control
- Plain Concrete with 5% of MIRHA
- Plain Concrete with Steel Fibre
- Plain Concrete with 5% of MIRHA and Steel Fibre

Plain Concrete (Control)

Grade Concrete	Cement (kg/m³)	Water(kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate(kg/m³)
25	362.10	210.00	511.80	1016.10
50.0	538.50	210.00	421.10	1230.40
70.0	700.00	210.00	357.60	1132.40

Table 4.4: *Plain Concrete as Control*

Plain Concrete + MIRHA (5%)

Grade Concrete	Cement (kg/m³)	MIRHA (kg/m³)	Water(kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate(kg/m³)
25	344.00	18.11	210.00	511.80	1016.10
50.0	511.58	26.93	210.00	421.10	1230.40
70.0	665.00	35.00	210.00	357.60	1132.40

Table 4.5: *Plain Concrete with MIRHA*

Steel Fibre

% vol. of Steel Fibre	Weight of Steel Fibre (kg/m³)
0.3	7.2
0.5	12.0
0.8	19.2

density of concrete = 2400 kg/m³

Table 4.6: *Proportion of Steel Fibre*

4.2 Compressive Strength

Basically, the compressive strength for normal (plain) concrete of grade 25 have be around 25 to 30 N/mm^2 while grade 50 is around 50 N/mm^2 and grade 70 is around 70 N/mm^2.

Please refer to Appendix A for the total detailed result of compressive strength for plain concrete as control sample.

Here are the details that been used for determine the compressive properties of the concrete in this study:-

- Sample Dimension :- 150 x 150 x 150 mm
- Pace Rate :- 6.80 kN/s

Overall, the compressive strength is slightly affected by the presence of steel fibres, with observed increases ranging from 0 to 15%. It is also interesting to observe that the cubes containing 0.5% steel fibers gave higher strength results than those containing 0.3% and 0.8% of steel fibres since the presence of 0.5% steel fibre improved about 10 to 15% while the presence of 0.8% steel fibre only improved around 3 to 8% and the presence of 0.3% steel fibre slightly improved about 1 to 3% of compressive strength of concrete. This is because the use of higher fiber volume fractions leads to fibre balling and irregular distribution of the fibers within the mix and thus reduces the strength of the matrix.

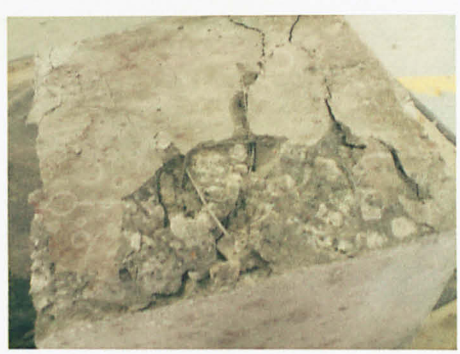


Figure 4.1: *Comparison between Control Sample and presence of Steel Fibre*

Figure 4.2: Balling of fibres

Please refer to Appendix C for the total detailed result of compressive strength for the concrete after introducing the 0.3%, 0.5% and 0.8% of steel fibre.

Grade 25

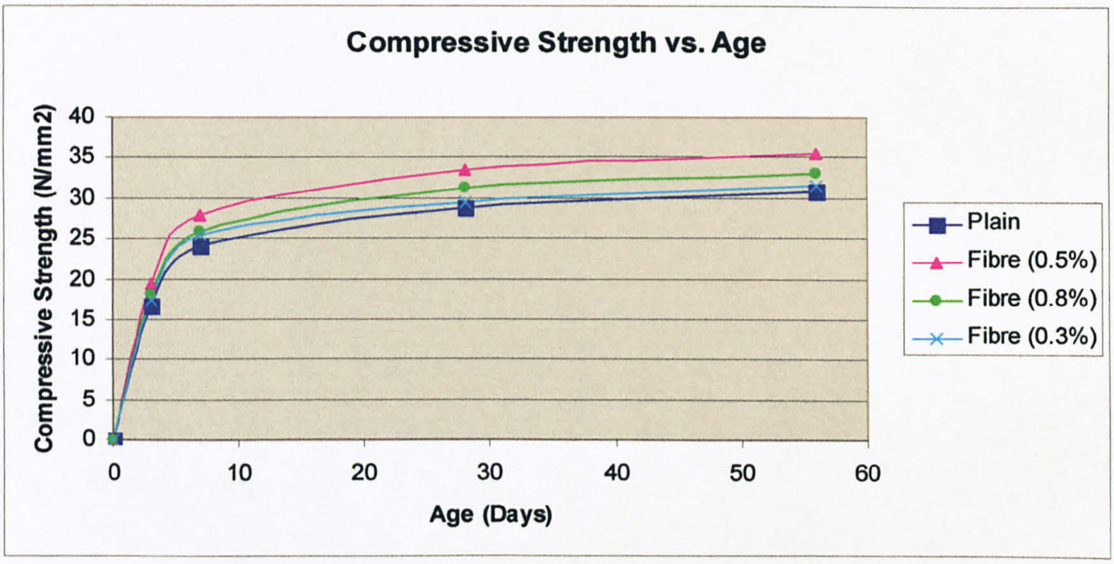


Figure 4.3: *Comparison Compressive Strength for Grade 25 between Control Sample and presence of Steel Fibre*

Grade 50

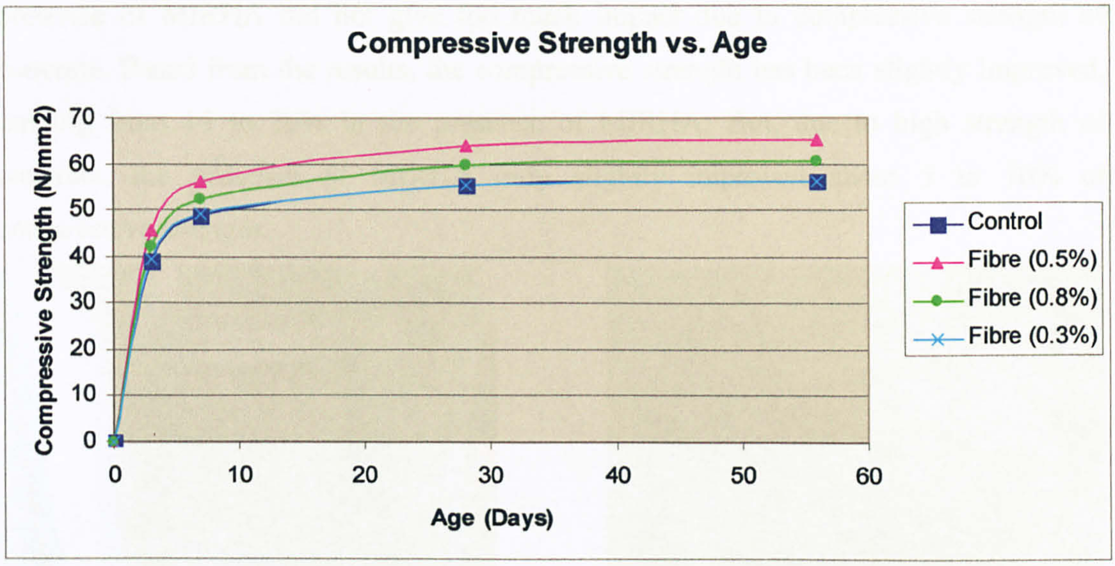


Figure 4.4: *Comparison Compressive Strength for Grade 50 between Control Sample and presence of Steel Fibre*

Grade 70

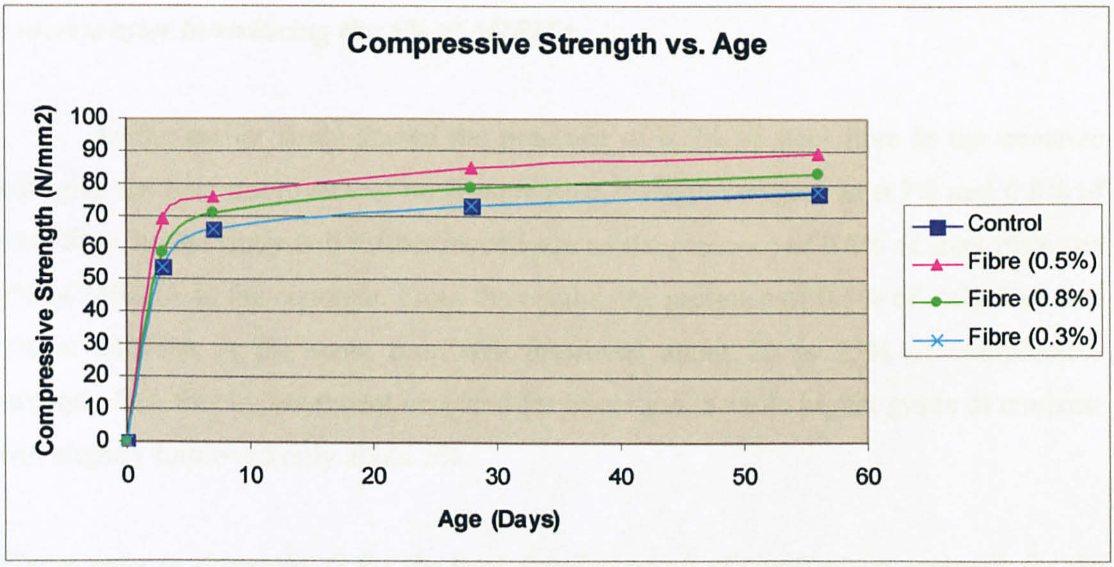


Figure 4.5: *Comparison Compressive Strength for Grade 70 between Control Sample and presence of Steel Fibre*

As it has been proven that the best proportion of MIRHA presence in concrete is about 5% in the previous research, so the study only focus on this percentage. The presence of MIRHA did not give too much impact due to compressive strength of concrete. Based from the results, the compressive strength has been slightly improved, ranging from 15 to 20% in the presence of MIRHA. But, due to high strength of concrete, the presence of MIRHA only slightly improved about 5 to 10% of compressive strength.

Figure 4.6: *Comparison between Control Sample and presence of MIRHA*

Please refer to Appendix E for the total detailed result of compressive strength for the concrete after introducing the 5% of MIRHA.

As the earlier study shown the presence of 0.5% of steel fibre in the concrete will give the best improvement on compressive strength compare to 0.3% and 0.8% of steel fibre, so the study will further investigate on the presence of 0.5% of steel fibre and 5% of MIRHA in the concrete. From the results, the presence of 0.5% of steel fibre and 5% of MIRHA at the same time will improved about 20 to 25% of compressive strength. But, this improvement occurred for lower grade while higher grade of concrete will slightly improved only about 5%.

Please refer to Appendix G for the total detailed result of compressive strength for the concrete after introducing the 0.5% of steel fibre and 5% of MIRHA.

Grade 25

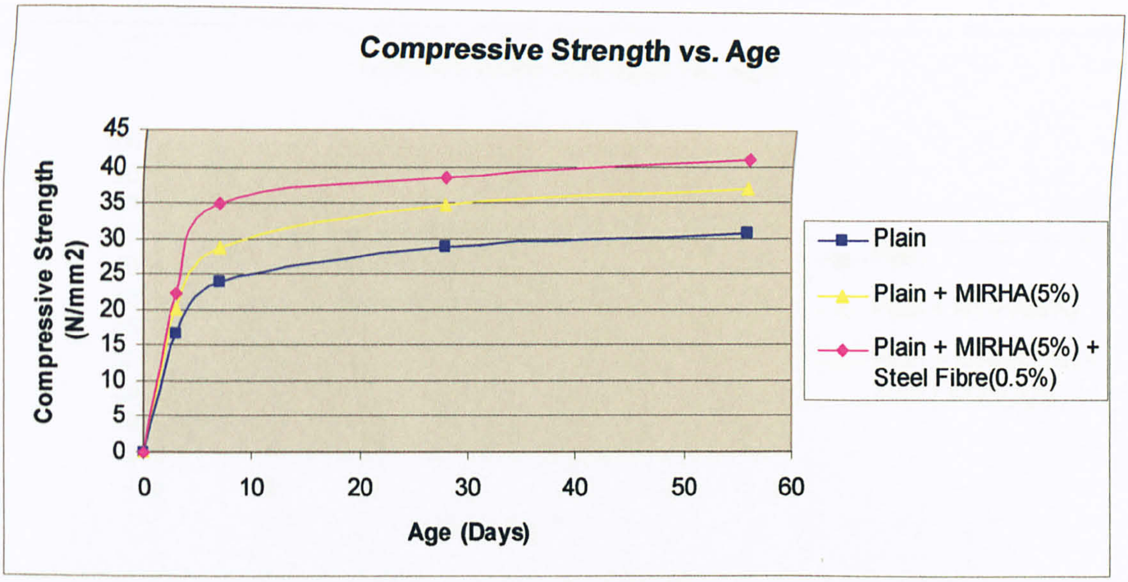


Figure 4.7: *Comparison Compressive Strength for Grade 25 between Control Sample and presence of Steel Fibre and MIRHA*

Grade 50

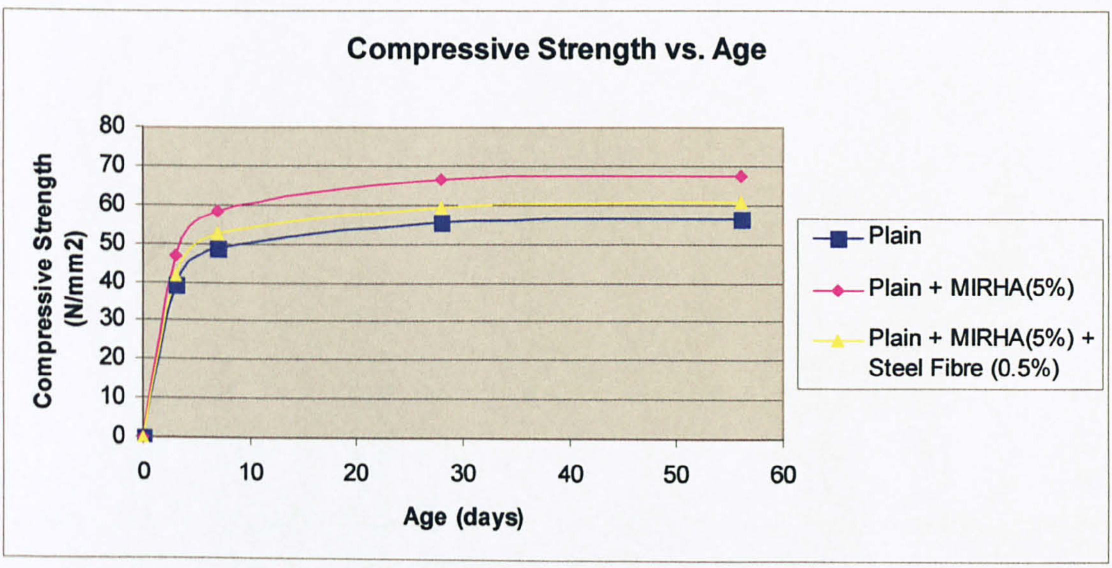


Figure 4.8: *Comparison Compressive Strength for Grade 50 between Control Sample and presence of Steel Fibre and MIRHA*

Grade 70

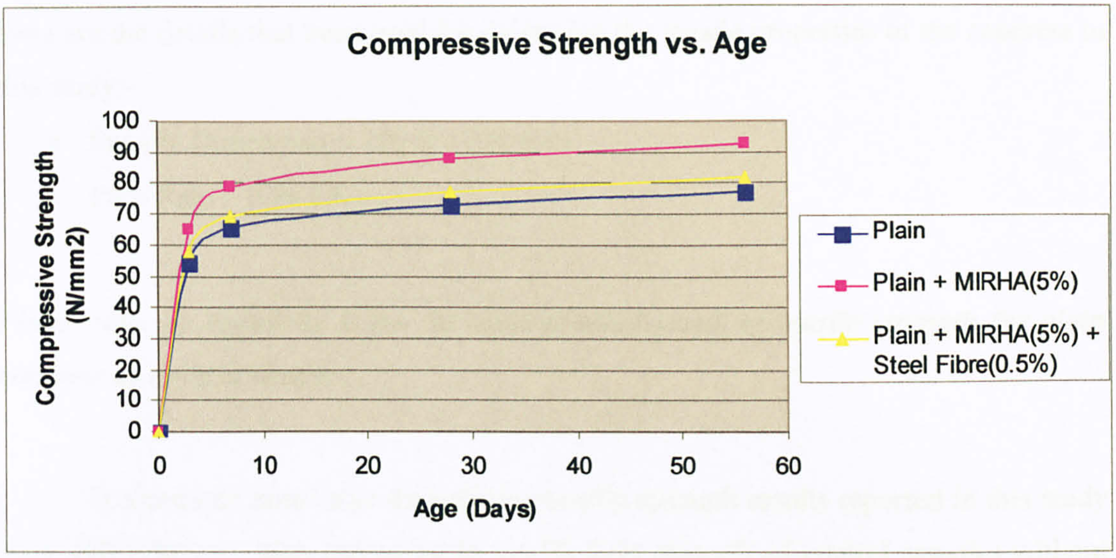


Figure 4.9: *Comparison Compressive Strength for Grade 70 between Control Sample and presence of Steel Fibre and MIRHA*

4.3 Tensile Strength

Here are the details that been used for determine the tensile properties of the concrete in this study:-

- Sample Dimension :- 100 ϕ x 200 mm
- Pace Rate :- 0.94 kN/s

Please refer to Appendix B for the total detailed result of tensile strength for plain concrete as control sample.

It should be noted that the splitting tensile strength results reported in this study were still relatively high compared to the 28 days strength of control samples without steel fibers and MIRHA. Basically, the tensile strength of concrete improved significantly about 30 to 40% compared to control samples. This improvement only occurred on the samples with additional of 0.5% of steel fibre while additional of 0.8% of steel fibre about 20 to 30% only and 0.3% of steel fibre slightly about 5 to 10%.

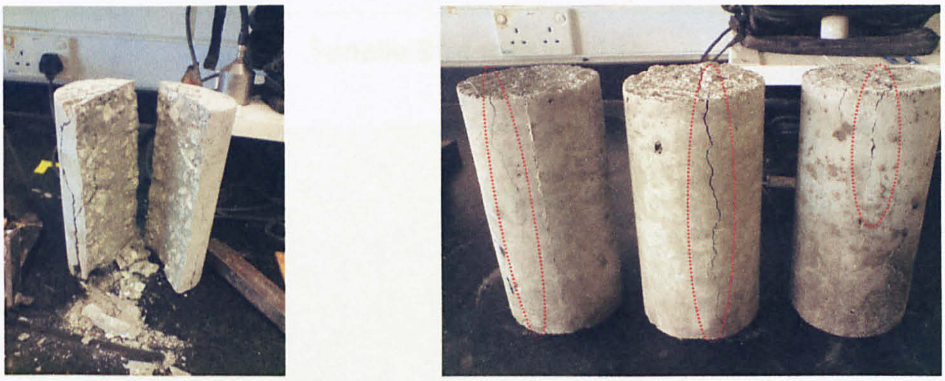


Figure 4.10: Comparison between Control Sample and presence of Steel Fibre

Please refer to Appendix D for the total detailed result of tensile strength for the concrete after introducing the0.3%, 0.5% and 0.8% of steel fibre.

Grade 25

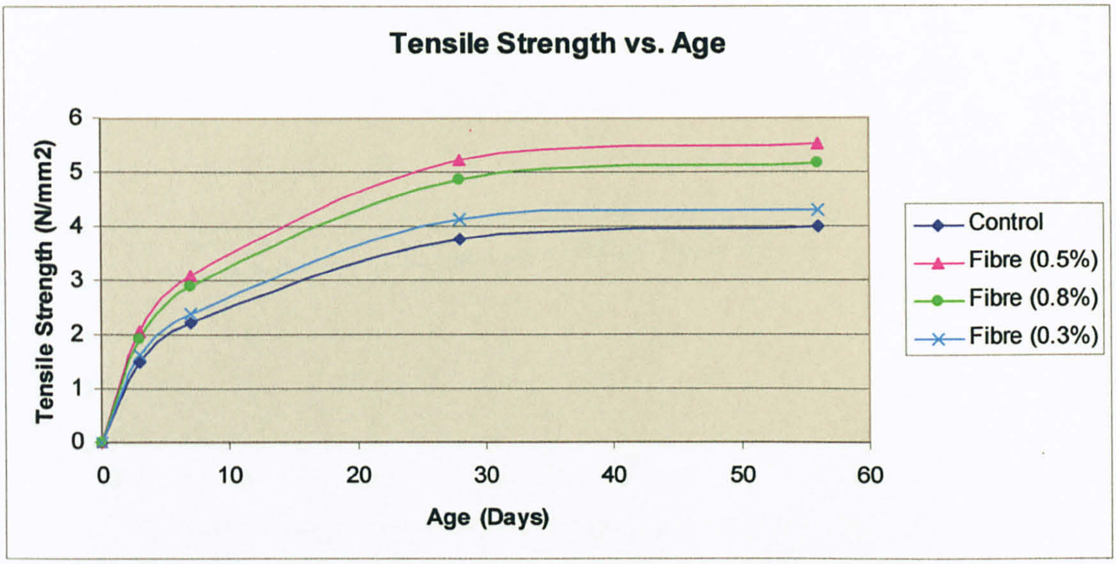


Figure 4.11: *Comparison Tensile Strength for Grade 25 between Control Sample and presence of Steel Fibre*

Grade 50

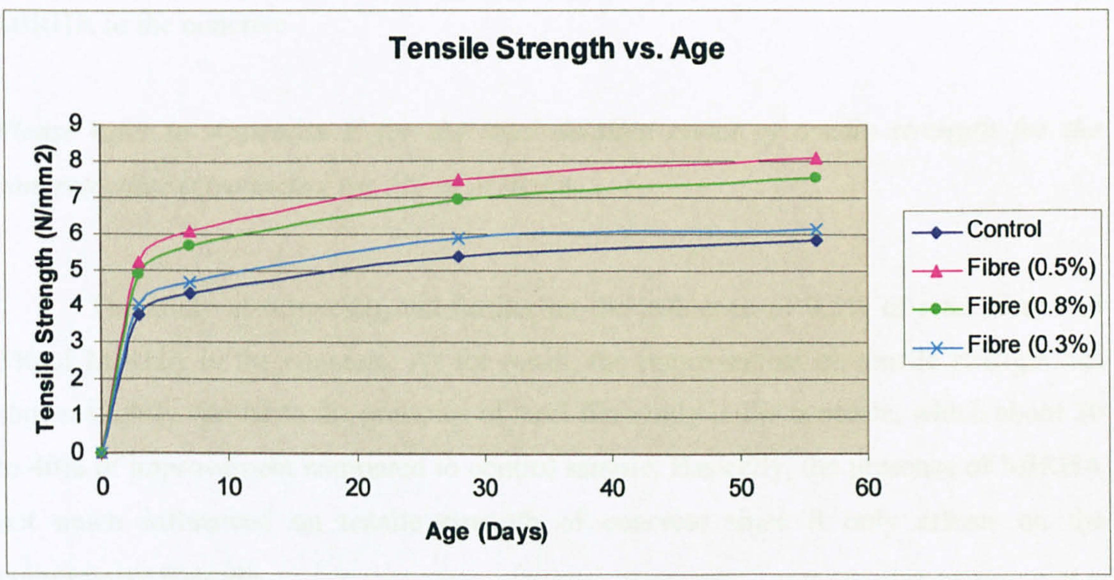


Figure 4.12: *Comparison Tensile Strength for Grade 50 between Control Sample and presence of Steel Fibre*

Grade 70

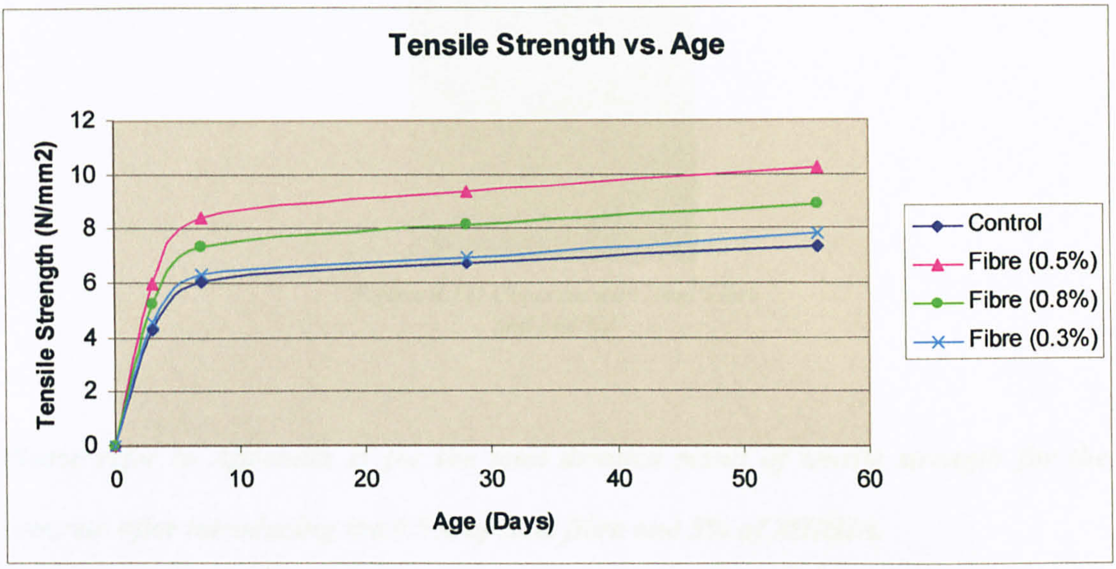


Figure 4.13: *Comparison Tensile Strength for Grade 70 between Control Sample and presence of Steel Fibre*

The results also shown no or slightly improvement on tensile strength compare to control sample only about 0 to 5% for all grade of concretes after introducing the MIRHA to the concrete.

Please refer to Appendix F for the total detailed result of tensile strength for the concrete after introducing the 5% of MIRHA.

The study also investigated further on the influence of 0.5% of steel fibre and 5% of MIRHA in the concrete. As for result, the improvement on tensile strength has shown slightly similar to the presence of steel fibre only in the concrete, which about 30 to 40% of improvement compared to control sample. Basically, the presence of MIRHA not much influenced on tensile strength of concrete since it only affects on the compressive strength.

Figure 4.14: Concrete with Steel Fibre and MIRHA

Please refer to Appendix H for the total detailed result of tensile strength for the concrete after introducing the 0.5% of steel fibre and 5% of MIRHA.

Grade 25

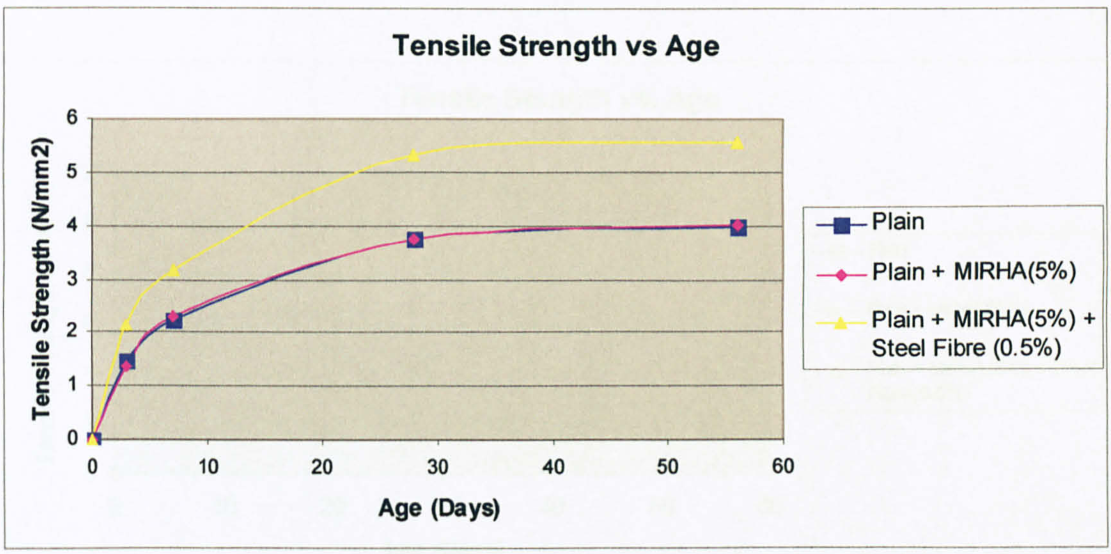


Figure 4.15: *Comparison Tensile Strength for Grade 25 between Control Sample and presence of Steel Fibre and MIRHA*

Grade 50

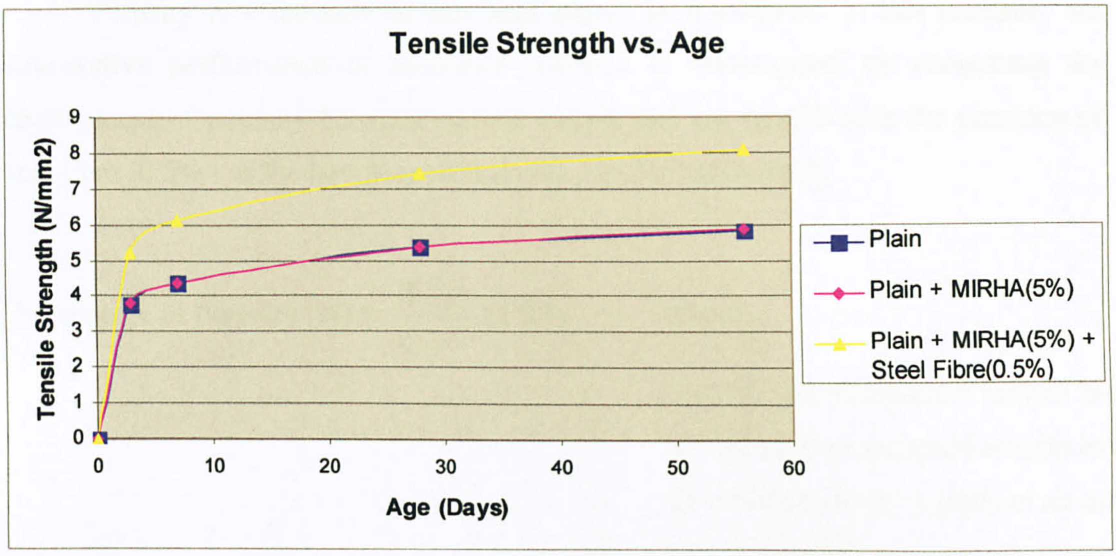


Figure 4.16: *Comparison Tensile Strength for Grade 25 between Control Sample and presence of Steel Fibre and MIRHA*

Grade 70

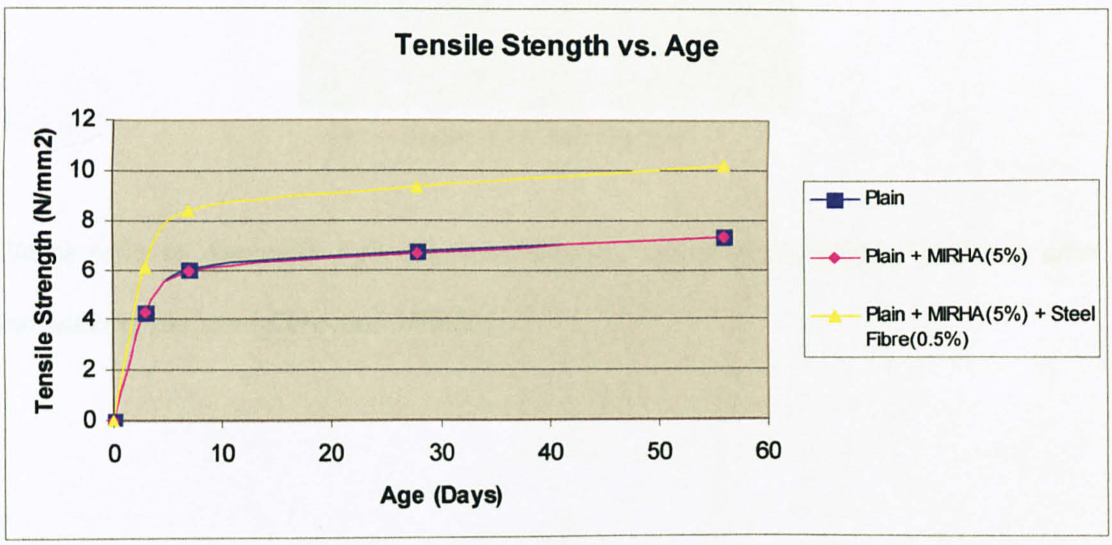


Figure 4.17: *Comparison Tensile Strength for Grade 25 between Control Sample and presence of Steel Fibre and MIRHA*

4.4 Porosity

Porosity is a measure of the void spaces in a material. In this research, the comparative performance of hardened concrete is investigated by comparing the development of porosity between control sample and the sample with the presence of steel fibre (0.5% - as the best proportion) with / and MIRHA (5%).

$$\text{Percentage of Porosity (\%)} = \frac{B-D}{B-C} X100\%$$

Where;

B = Weight of saturated sample in air

C = Weight of saturated sample in water

D = Weight of dry sample in air (after put in oven)

Figure 4.18: Porosity Test

Please refer to Appendix I for the total detailed result of porosity of concrete after introducing the steel fibre and MIRHA.

Grade 25

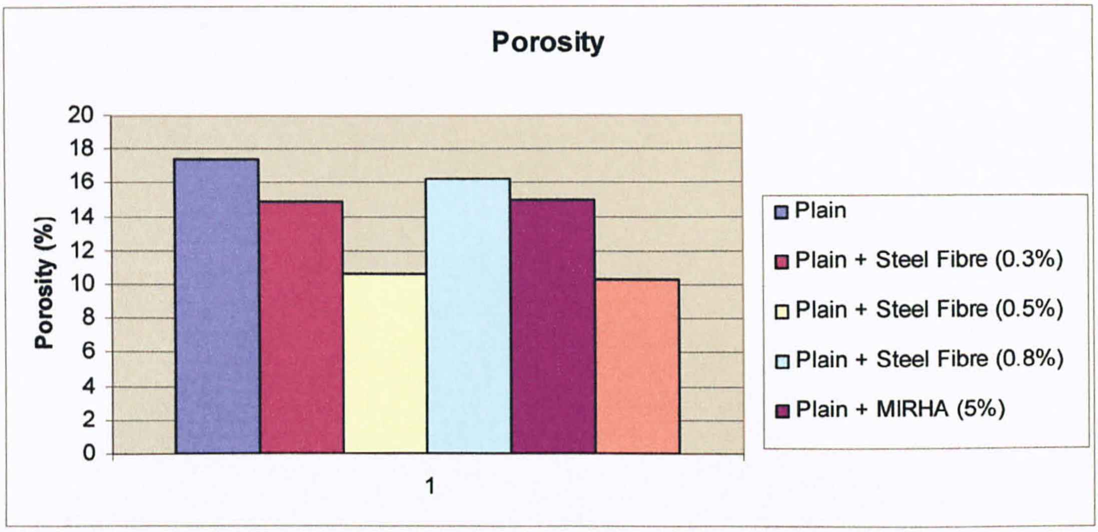


Figure 4.19: *Comparison Porosity between Control Sample and presence of Steel Fibre and MIRHA*

Grade 50

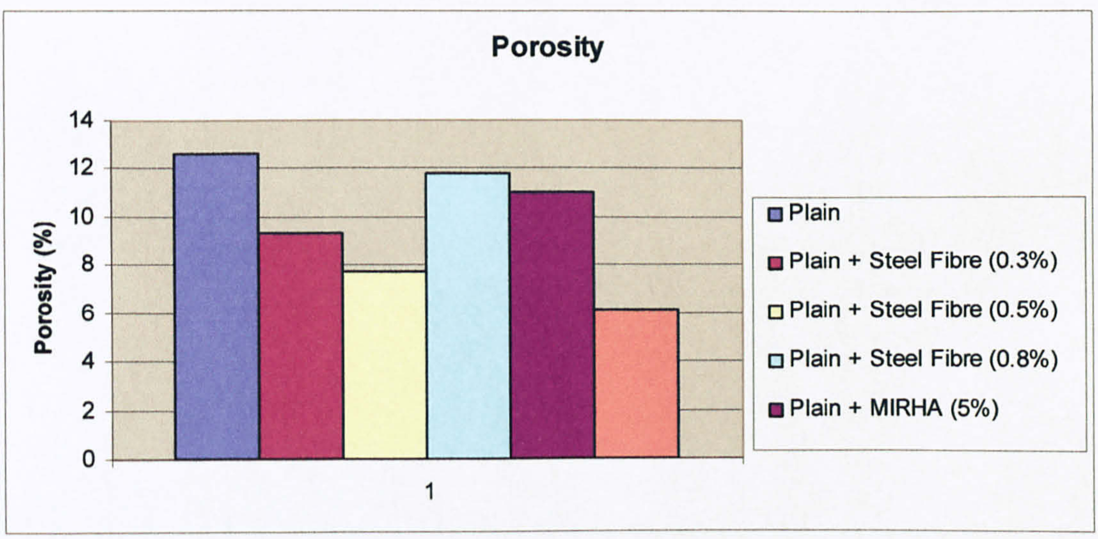


Figure 4.20: *Comparison Porosity between Control Sample and presence of Steel Fibre and MIRHA*

Grade 70

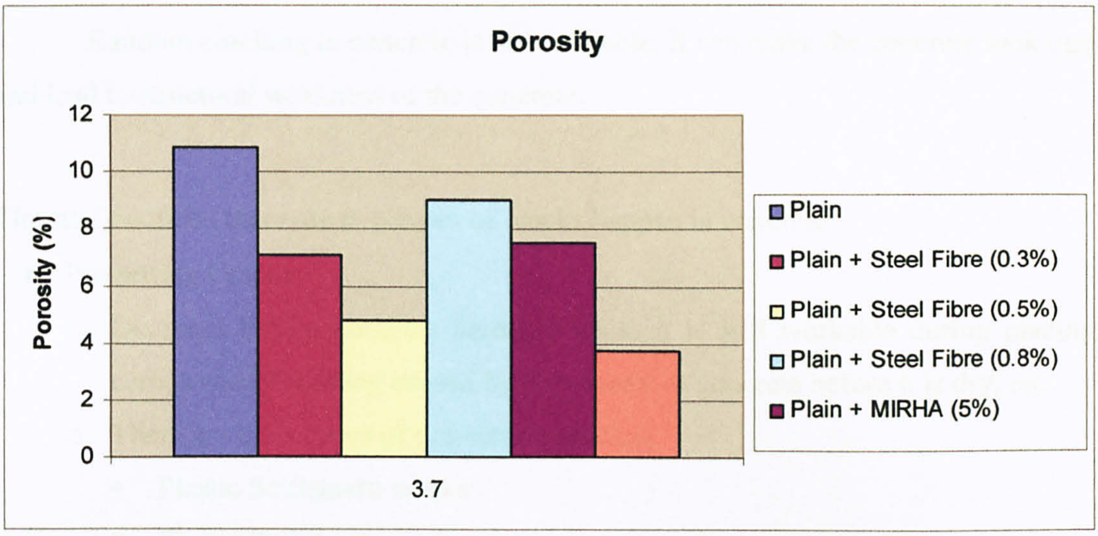


Figure 4.21: Comparison Porosity between Control Sample and presence of Steel Fibre and MIRHA

4.5 Crack Pattern

Random cracking in concrete is not desirable. It can make the concrete look ugly and lead to structural weakness of the concrete.

The study noticed there are two types of cracks happen in concrete:-

- Pre-setting Cracks
  - Occurred before concrete hardens, while it is still workable during placing, compaction, finishing caused by movement of concrete before it is dry, etc.
  - There are three types of pre-setting cracks:-
    - Plastic Settlement cracks
    - Plastic Shrinkage cracks
    - Cracks caused by movement of the formwork
- Hardened Cracking
  - Occurred after concrete hardens which may be caused by drying shrinkage, movement or settling of the ground, or placing higher loads on the concrete than it was designed to carry.

Cracks were induced to a specified displacement. The cracks then relaxed somewhat once they were unloaded. The unreinforced concrete (plain concrete) (Figure 4.22) shows the most crack relaxation even though in presence of MIRHA only. The cracks in the concrete with steel fibres (Figure 4.23) seemed to relax less. This indicates that the SFRC undergoes more inelastic deformation than the unreinforced concrete.

Figure 4.22: *Concrete without steel fibre as reinforcement*

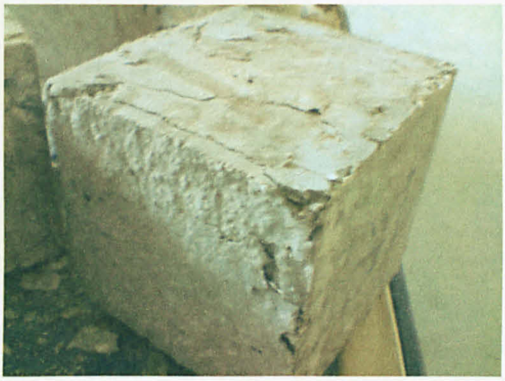


Figure 4.23: *Concrete with steel fibre as reinforcement*

At higher levels of cracking, steel reinforcing fibers clearly reduce porosity. This is most likely due to the stitching and multiple cracking effects that the steel fibers have. The steel fibers might stitch the cracks at the ends, perhaps shortening the length of the crack, and reducing the crack area. In addition, the steel fiber reinforcement changes the crack geometry from one large crack to multiple smaller cracks. The steel fibers distribute the stress evenly throughout the material.

Figure 4.24: *Concrete without steel fibre as reinforcement*

Figure 4.25: *Concrete with steel fibre as reinforcement*

However, at some fibre volume, an optimum might be reached. It is possible that a higher fiber volume will further reduce the strength while increase the porosity of concrete by occurred the steel fibre balling. This is because the higher proportion of steel fibre might cause them not even distributed after introducing into the fresh concrete.

Figure 4.26: *Balling of fibres*

CHAPTER 5

CONCLUSION

Based on the test results of this study, the following conclusion can be drawn:-

1. During the splitting tensile test at 28th days, the concrete of grade 25 with 0.5% of steel fibre had the highest improvement on tensile strength (about 35 to 40%) compared to other grades (G50 & G70) and also other proportions of steel fibre (0.3% & 0.8%). However, the test results showed that the presence of MIRHA has insignificant impact on the tensile strength of concrete.

2. The compressive test of concrete grade 25 with 5% of MIRHA at 28th days had the highest improvement on compressive strength (about 20%). Besides, the results also found that the presence of at least 0.5% steel fibre was sufficient to increase the strength of the concrete compared to the other proportions (0.3% & 0.8%). However, MIRHA had more effect on the compressive strength of the concrete.

3. Adding the steel fibre had significant effects on tensile strength of concrete. However at higher steel fibres content, the fibers might be unevenly distributed which may reduce the concrete strength. So, the probability of fibre balling occurred are higher at higher steel fiber content while the less steel fibres content only slightly improved about 0 to 3%.

4. Adding the steel fibre also help to resist the plastic and drying shrinkage of cracking of concrete. However, at some fiber volumes, an optimum condition might be obtained. In this study, the optimum proportion of steel fibre was at 0.5%.

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APPENDIX A

- **Plain Concrete as Control Samples**

  - **Compressive Strength Result**

Grade 25

Concrete Type:- Plain Concrete (Control)
Slump Test:- 105mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	8.10	2400.00	378.51	16.82
08/12/2008	15/12/2008	7	8.04	2382.22	542.23	24.10
08/12/2008	05/01/2009	28	8.05	2385.19	650.64	28.92
08/12/2008	02/02/2009	56	8.04	2382.22	691.34	30.74

Grade 50

Concrete Type:- Plain Concrete (Control)
Slump Test:- 97mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	8.23	2438.52	883.63	39.29
08/12/2008	15/12/2008	7	8.19	2426.67	1095.49	48.71
08/12/2008	05/01/2009	28	8.07	2391.11	1247.07	55.45
08/12/2008	02/02/2009	56	8.21	2432.59	1266.86	56.33

Grade 70

Concrete Type:- Plain Concrete (Control)
Slump Test:- 79mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	8.44	2500.74	1220.53	54.27
08/12/2008	15/12/2008	7	8.19	2426.67	1478.72	65.75
08/12/2008	05/01/2009	28	8.19	2426.67	1646.27	73.20
08/12/2008	02/02/2009	56	8.37	2480.00	1739.15	77.33

APPENDIX B

Plain Concrete as Control Samples

Tensile Strength Result

Grade 25

Concrete Type:- Plain Concrete (Control)
Slump Test:- 105mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	3.8	2418.84	47.04	1.49
08/12/2008	15/12/2008	7	3.65	2323.36	70.42	2.24
08/12/2008	05/01/2009	28	3.77	2399.75	118.13	3.76
08/12/2008	02/02/2009	56	3.87	2463.40	125.56	3.99

Grade 50

Concrete Type:- Plain Concrete (Control)
Slump Test:- 97mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	3.68	2342.46	118.51	3.77
08/12/2008	15/12/2008	7	3.66	2329.73	137.74	4.38
08/12/2008	05/01/2009	28	3.67	2336.09	169.00	5.38
08/12/2008	02/02/2009	56	3.71	2361.55	183.18	5.83

Grade 70

Concrete Type:- Plain Concrete (Control)
Slump Test:- 79mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	3.83	2437.94	136.41	4.34
08/12/2008	15/12/2008	7	3.78	2406.11	190.06	6.05
08/12/2008	05/01/2009	28	3.79	2412.48	211.59	6.73
08/12/2008	02/02/2009	56	3.77	2399.75	230.82	7.35

APPENDIX C

Effects of Steel Fibre on the characteristic of Concrete

- **Compressive Strength Result**

- **Grade 25**

Concrete Type:- Plain Concrete + Fibre (0.3%)
Slump Test:- 105mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	8.23	2438.52	390.33	17.35
08/12/2008	15/12/2008	7	8.22	2435.56	571.32	25.39
08/12/2008	05/01/2009	28	8.27	2450.37	663.78	29.50
08/12/2008	02/02/2009	56	8.17	2420.74	709.60	31.54

Concrete Type:- Plain Concrete + Fibre (0.5%)
Slump Test:- 87mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
09/12/2008	12/12/2008	3	8.19	2426.67	439.07	19.51
09/12/2008	16/12/2008	7	8.13	2408.89	628.99	27.95
09/12/2008	06/01/2009	28	8.14	2411.85	754.74	33.54
09/12/2008	03/02/2009	56	8.21	2432.59	801.95	35.64

Concrete Type:- Plain Concrete + Fibre (0.8%)
Slump Test:- 89mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
15/12/2008	18/12/2008	3	8.23	2438.52	408.79	18.17
15/12/2008	22/12/2008	7	8.19	2426.67	585.61	26.03
15/12/2008	12/01/2009	28	8.19	2426.67	702.69	31.23
15/12/2008	09/02/2009	56	8.17	2420.74	746.65	33.18

- **Grade 50**

Concrete Type:- Plain Concrete + Fibre (0.3%)
Slump Test:- 97mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	8.29	2456.30	889.96	39.55
08/12/2008	15/12/2008	7	8.22	2435.56	1107.11	49.20
08/12/2008	05/01/2009	28	8.37	2480.00	1251.37	55.62
08/12/2008	02/02/2009	56	8.34	2471.11	1268.33	56.37

Concrete Type:- Plain Concrete + Fibre (0.5%)
Slump Test:- 86mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
09/12/2008	12/12/2008	3	8.22	2435.56	1025.01	45.56
09/12/2008	16/12/2008	7	8.27	2450.37	1270.77	56.48
09/12/2008	06/01/2009	28	8.31	2462.22	1446.60	64.29
09/12/2008	03/02/2009	56	8.19	2426.67	1469.56	65.31

Concrete Type:- Plain Concrete + Fibre (0.8%)
Slump Test:- 81mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
15/12/2008	18/12/2008	3	8.25	2444.44	954.32	42.41
15/12/2008	22/12/2008	7	8.33	2468.15	1183.13	52.58
15/12/2008	12/01/2009	28	8.29	2456.30	1346.84	59.86
15/12/2008	09/02/2009	56	8.29	2456.30	1368.21	60.81

- **Grade 70**

Concrete Type:- Plain Concrete + Fibre (0.3%)
Slump Test:- 79mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	8.42	2494.81	1222.95	54.35
08/12/2008	15/12/2008	7	8.37	2480.00	1481.33	65.84
08/12/2008	05/01/2009	28	8.19	2426.67	1649.33	73.30
08/12/2008	02/02/2009	56	8.22	2435.56	1741.24	77.39

Concrete Type:- Plain Concrete + Fibre (0.5%)
Slump Test:- 73mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
09/12/2008	12/12/2008	3	8.47	2509.63	1415.81	69.25
09/12/2008	16/12/2008	7	8.33	2468.15	1715.32	76.24
09/12/2008	06/01/2009	28	8.33	2468.15	1909.67	84.87
09/12/2008	03/02/2009	56	8.39	2485.93	2017.41	89.66

Concrete Type:- Plain Concrete + Fibre (0.8%)
Slump Test:- 69mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
15/12/2008	18/12/2008	3	8.45	2503.70	1318.17	58.59
15/12/2008	22/12/2008	7	8.41	2491.85	1597.02	70.98
15/12/2008	12/01/2009	28	8.37	2480.00	1777.97	79.02
15/12/2008	09/02/2009	56	8.35	2474.07	1878.28	83.48

APPENDIX D

Effects of Steel Fibre on the characteristic of Concrete

- **Tensile Strength Result**

- **Grade 25**

Concrete Type:- Plain Concrete + Fibre (0.3%)
Slump Test:- 93mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	3.71	2361.55	50.76	1.62
08/12/2008	15/12/2008	7	3.66	2329.73	75.51	2.40
08/12/2008	05/01/2009	28	3.72	2367.92	129.71	4.13
08/12/2008	02/02/2009	56	3.70	2355.19	135.23	4.30

Concrete Type:- Plain Concrete + Fibre (0.5%)
Slump Test:- 87mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
09/12/2008	12/12/2008	3	3.88	2469.76	65.07	2.07
09/12/2008	16/12/2008	7	3.68	2342.46	97.83	3.11
09/12/2008	06/01/2009	28	3.71	2361.55	164.21	5.23
09/12/2008	03/02/2009	56	3.68	2342.46	174.26	5.55

Concrete Type:- Plain Concrete + Fibre (0.8%)
Slump Test:- 89mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
15/12/2008	18/12/2008	3	3.79	2412.48	60.63	1.93
15/12/2008	22/12/2008	7	3.81	2425.21	91.14	2.90
15/12/2008	12/01/2009	28	3.89	2476.13	152.99	4.87
15/12/2008	09/02/2009	56	3.75	2387.01	162.35	5.17

- **Grade 50**

Concrete Type:- Plain Concrete + Fibre (0.3%)
Slump Test:- 89mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	3.71	2361.55	128.00	4.07
08/12/2008	15/12/2008	7	3.60	2291.53	146.33	4.66
08/12/2008	05/01/2009	28	3.77	2399.75	184.21	5.86
08/12/2008	02/02/2009	56	3.71	2361.55	192.34	6.12

Concrete Type:- Plain Concrete + Fibre (0.5%)
Slump Test:- 86mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
09/12/2008	12/12/2008	3	3.75	2387.01	164.65	5.24
09/12/2008	16/12/2008	7	3.77	2399.75	191.29	6.09
09/12/2008	06/01/2009	28	3.71	2361.55	234.88	7.48
09/12/2008	03/02/2009	56	3.74	2380.65	254.62	8.10

Concrete Type:- Plain Concrete + Fibre (0.8%)
Slump Test:- 81mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
15/12/2008	18/12/2008	3	3.71	2361.55	153.4	4.88
15/12/2008	22/12/2008	7	3.67	2336.09	178.22	5.67
15/12/2008	12/01/2009	28	3.69	2348.82	218.82	6.96
15/12/2008	09/02/2009	56	3.75	2387.01	237.22	7.55

❖ **Grade 70**

Concrete Type:- Plain Concrete + Fibre (0.3%)
Slump Test:- 75mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
08/12/2008	11/12/2008	3	3.89	2476.13	144.31	4.59
08/12/2008	15/12/2008	7	3.78	2406.11	199.56	6.35
08/12/2008	05/01/2009	28	3.81	2425.21	217.94	6.94
08/12/2008	02/02/2009	56	3.77	2399.75	244.61	7.79

Concrete Type:- Plain Concrete + Fibre (0.5%)
Slump Test:- 73mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
09/12/2008	12/12/2008	3	3.77	2399.75	189.54	6.03
09/12/2008	16/12/2008	7	3.87	2463.40	264.23	8.41
09/12/2008	06/01/2009	28	3.82	2431.57	293.92	9.35
09/12/2008	03/02/2009	56	3.82	2431.57	321.00	10.22

Concrete Type:- Plain Concrete + Fibre (0.8%)
Slump Test:- 69mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
15/12/2008	18/12/2008	3	3.88	2469.76	164.99	5.25
15/12/2008	22/12/2008	7	3.75	2387.01	230.01	7.32
15/12/2008	12/01/2009	28	3.81	2425.21	255.86	8.14
15/12/2008	09/02/2009	56	3.85	2450.67	279.43	8.89

APPENDIX E

Effects of MIRHA on the characteristic of Concrete

Compressive Strength Result

Grade 25

Concrete Type:- Plain + MIRHA (5%)
Slump Test:- 100mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
16/12/2008	19/12/2008	3	7.92	454.21	435.29	20.19
16/12/2008	23/12/2008	7	7.74	650.68	607.39	28.92
16/12/2008	13/12/2008	28	8.05	780.77	761.33	34.70
16/12/2008	10/2/2009	56	8.01	829.61	799.21	36.87

Grade 50

Concrete Type:- Plain + MIRHA (5%)
Slump Test:- 95mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
16/12/2008	19/12/2008	3	8.11	2402.96	1060.36	47.13
16/12/2008	23/12/2008	7	8.22	2435.56	1314.59	58.43
16/12/2008	13/12/2008	28	8.19	2426.67	1496.48	66.51
16/12/2008	10/2/2009	56	8.16	2417.78	1520.23	67.57

Grade 70

Concrete Type:- Plain + MIRHA (5%)
Slump Test:- 78mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
16/12/2008	19/12/2008	3	8.44	2500.74	1464.64	65.09
16/12/2008	23/12/2008	7	8.19	2426.67	1774.46	78.87
16/12/2008	13/12/2008	28	8.19	2426.67	1975.52	87.80
16/12/2008	10/2/2009	56	8.37	2480.00	2086.98	92.75

APPENDIX F

- **Effects of MIRHA on the characteristic of Concrete**

  - **Tensile Strength Result**

Grade 25

Concrete Type:- Plain + MIRHA (5%)
Slump Test:- 100mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
16/12/2008	19/12/2008	3	3.77	2399.75	43.05	1.37
16/12/2008	23/12/2008	7	3.65	2323.36	72.58	2.31
16/12/2008	13/12/2008	28	3.81	2425.21	118.14	3.76
16/12/2008	10/2/2009	56	3.78	2406.11	126.62	4.03

Grade 50

Concrete Type:- Plain + MIRHA (5%)
Slump Test:- 95mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
16/12/2008	19/12/2008	3	3.68	2342.46	111.97	3.81
16/12/2008	23/12/2008	7	3.67	2336.09	137.31	4.37
16/12/2008	13/12/2008	28	3.73	2374.28	169.67	5.40
16/12/2008	10/2/2009	56	3.66	2329.73	184.75	5.88

Grade 70

Concrete Type:- Plain + MIRHA (5%)
Slump Test:- 78mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
16/12/2008	19/12/2008	3	3.81	2425.21	136.05	4.33
16/12/2008	23/12/2008	7	3.81	2425.21	188.52	6.00
16/12/2008	13/12/2008	28	3.74	2380.65	210.20	6.69
16/12/2008	10/2/2009	56	3.79	2412.48	231.25	7.36

APPENDIX G

Effects of Steel Fibre and MIRHA on the characteristic of Concrete

Compressive Strength Result

Grade 25

Concrete Type:- Plain Concrete + MIRHA (5%) + Fibre (0.5%)
Slump Test:- 82mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
2/2/2009	5/2/2009	3	8.15	2414.81	503.42	22.37
2/2/2009	9/2/2009	7	8.09	2397.04	721.17	35.05
2/2/2009	2/3/2009	28	8.11	2402.96	865.35	38.46
2/2/2009	30/03/2009	56	8.07	2391.11	919.48	40.87

Grade 50

Concrete Type:- Plain Concrete + MIRHA (5%) + Fibre (0.5%)
Slump Test:- 78mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
2/2/2009	5/2/2009	3	8.17	2420.74	1175.22	52.23
2/2/2009	9/2/2009	7	8.22	2435.56	1457.00	64.76
2/2/2009	2/3/2009	28	8.21	2432.59	1658.60	73.72
2/2/2009	30/03/2009	56	8.13	2408.89	1684.92	74.89

Grade 70

Concrete Type:- Plain Concrete + MIRHA (5%) + Fibre (0.5%)
Slump Test:- 68mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
2/2/2009	5/2/2009	3	8.25	2444.44	1623.30	72.15
2/2/2009	9/2/2009	7	8.31	2462.22	1966.70	87.41
2/2/2009	2/3/2009	28	8.33	2468.15	2189.54	97.31
2/2/2009	30/03/2009	56	8.37	2480.00	2313.10	102.80

APPENDIX H

Effects of Steel Fibre and MIRHA on the characteristic of Concrete

- **Tensile Strength Result**

Grade 25

Concrete Type:- Plain Concrete + MIRHA (5%) + Fibre (0.5%)
Slump Test:- 82mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
2/2/2009	5/2/2009	3	3.81	2425.21	66.92	2.13
2/2/2009	9/2/2009	7	3.77	2399.75	100.54	3.2
2/2/2009	2/3/2009	28	3.79	2412.48	167.47	5.33
2/2/2009	30/03/2009	56	3.91	2488.86	175.01	5.57

Grade 50

Concrete Type:- Plain Concrete + MIRHA (5%) + Fibre (0.5%)
Slump Test:- 78mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
2/2/2009	5/2/2009	3	3.71	2361.55	164.96	5.25
2/2/2009	9/2/2009	7	3.67	2336.09	193.23	6.15
2/2/2009	2/3/2009	28	3.75	2387.01	234.08	7.45
2/2/2009	30/03/2009	56	3.69	2348.82	254.82	8.11

Grade 70

Concrete Type:- Plain Concrete + MIRHA (5%) + Fibre (0.5%)
Slump Test:- 68mm

Date Casting	Date Test	Age (Days)	Weight (kg)	Weight/Vol (kg/m3)	Fail Load (kN)	Strength (N/mm2)
2/2/2009	5/2/2009	3	3.83	2437.94	191.76	6.11
2/2/2009	9/2/2009	7	3.81	2425.21	263.61	8.39
2/2/2009	2/3/2009	28	3.79	2412.48	294.09	9.36
2/2/2009	30/03/2009	56	3.81	2425.21	320.80	10.21

APPENDIX I

- **Porosity**
  - **Grade 25**

Sample	Weight of Saturated Specimen		Weight of Dry Specimen	Percentage of Porosity (%)
	In Air (g)	In Water (g)	In Air (g)	
	A	B	C	D
Plain	171.3	89.2	157	17.4
Plain + Steel Fibre (0.3%)	164.2	85.3	152.3	14.9
Plain + Steel Fibre (0.5%)	155.6	55.8	145	10.6
Plain + Steel Fibre (0.8%)	251.3	141.3	233.5	16.2
Plain + MIRHA (5%)	210.9	129	198.6	15.0
Plain + MIRHA (5%) + Steel Fibre (0.5%)	186	73.9	174.5	10.3

❖ **Grade 50**

Sample	Weight of Saturated Specimen		Weight of Dry Specimen	Percentage of Porosity (%)
	In Air (g)	In Water (g)	In Air (g)	
	A	B	C	D
Plain	177.9	77.5	155.2	12.6
Plain + Steel Fibre (0.3%)	181.9	68.5	171.3	9.3
Plain + Steel Fibre (0.5%)	153.3	49.3	145.3	7.7
Plain + Steel Fibre (0.8%)	208.2	86.8	193.9	11.8
Plain + MIRHA (5%)	196.6	79.3	183.7	11.0
Plain + MIRHA (5%) + Steel Fibre (0.5%)	287.7	129.3	278.1	6.1

❖ **Grade 70**

Sample	Weight of Saturated Specimen		Weight of Dry Specimen	Percentage of Porosity (%)
	In Air (g)	In Water (g)	In Air (g)	
A	B	C	D	E
Plain	170.3	41.3	156.3	10.9
Plain + Steel Fibre (0.3%)	165.8	40.9	156.9	7.1
Plain + Steel Fibre (0.5%)	167.3	43.3	161.3	4.8
Plain + Steel Fibre (0.8%)	160.9	39.1	149.9	9.0
Plain + MIRHA (5%)	196.6	69.0	187.1	7.5
Plain + MIRHA (5%) + Steel Fibre (0.5%)	256.9	72.8	250	3.7